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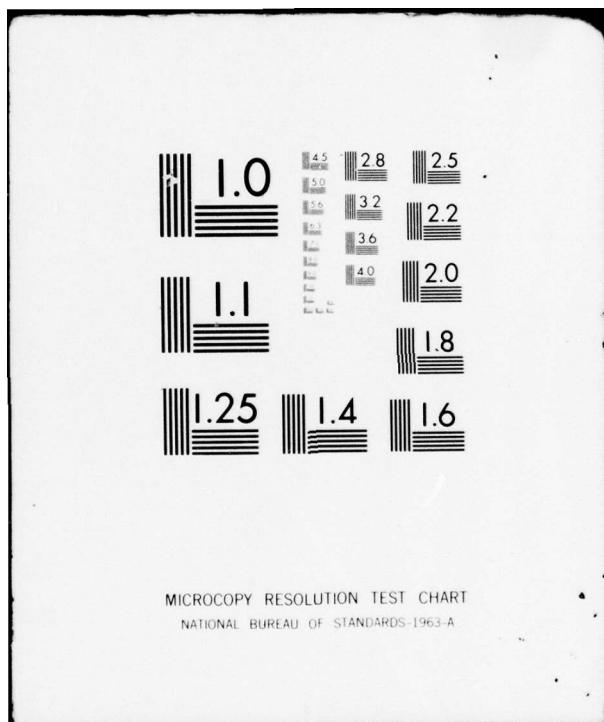
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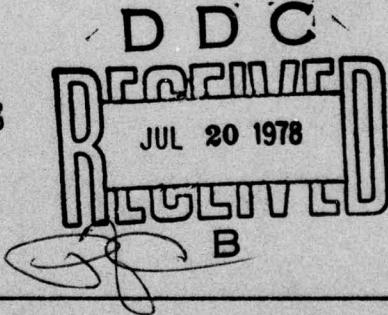
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TECHNICAL REPORT ARBRL-TR-02066

STANDARDIZATION OF TERMINAL BALLISTICS  
TESTING, DATA STORAGE AND RETRIEVAL

J. P. Lambert  
B. E. Ringers

May 1978



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER <i>(14)</i> BRL TECHNICAL REPORT ARBRL-TR-02066	2. GOVT ACCESSION NO. <i>V</i>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STANDARDIZATION OF TERMINAL BALLISTICS TESTING, DATA STORAGE AND RETRIEVAL.	5. TYPE OF REPORT & PERIOD COVERED <i>(9) Final report</i>	
6. AUTHOR(s) J. P. Lambert B. E. Ringers	7. CONTRACT OR GRANT NUMBER(s)	
8. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory ATTN: DRDAR-BLT Aberdeen Proving Ground, MD 21005	9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS <i>(16)</i> RDT&E 1L662618AH80	
10. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command US Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005	11. REPORT DATE <i>(14) May 78</i>	
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. NUMBER OF PAGES 83	
14. SECURITY CLASS. (of this report)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	<i>(13) 72 p.</i>	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.	<i>(16) SBIE</i> <i>(17) AD-E434 002</i>	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) ballistic data data base striking velocity $V_s$ , $V_r$ curve terminal ballistics	<i>(1)</i>	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (hib/lrs) The objectives of this report are to establish a systematic procedural basis for conducting terminal ballistics tests and to ascertain the data appropriate for storage in the TBD Penetrator Data Base. Chief concerns are the development of an experimental testing strategy, the definition of relevant terminal ballistics terminology, and the selection and organization of data.	<i>(1)</i>	

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## I. INTRODUCTION

Our purpose in this report is to present a routine, effective and workable set of methods applicable to the performance and documentation of terminal ballistics testing, specifically  $V_s$ ,  $V_r$  testing\*. Such testing, used to determine ballistic limit velocity ( $V_L$ ) and assess dependence of residual velocity ( $V_r$ ) on striking velocity ( $V_s$ ) for given projectile/target setups, supplies valuable characterizations of the projectile/target situations concerned and comprises a major effort in terminal ballistics experimentation.

In order that  $V_s$ ,  $V_r$  testing be efficient, approximately replicable, and attendant to quality assurance, there is a clear need for the establishment of procedural standardization in its conduct. There is an allied need to define terminology and to set conventions for data assimilation; it is intended that reasonably comprehensive standard collections of test data can be routinely inserted in a computerized storage and retrieval system so that data may be readily and selectively exploited as desired.

The objectives then are to suggest a structured methodology for testing, define relevant terminology, select a basic list of pertinent data and devise an organized format for its documentation.

Our treatment here is of but modest generality though amenable to expansion; by no means do we touch on all concerns that can be associated with  $V_s$ ,  $V_r$  testing. For instance, the characteristics of behind-armor debris often (and increasingly) require determination and documentation though this is an area not considered here. The effort to date has primarily been concerned with long rod penetrators. Further experimentation, usage and insight will no doubt suggest necessary and desirable modifications to handle diverse impact situations.

## II. PROCEDURE FOR $V_s$ , $V_r$ TESTING

This section describes the procedure to be followed in conducting a  $V_s$ ,  $V_r$  test. A flowchart which parallels this description is shown in Figures 1a, 1b, and 1c.

\*The term " $V_s$ ,  $V_r$  test" and other pertinent concepts are defined in Section IV.

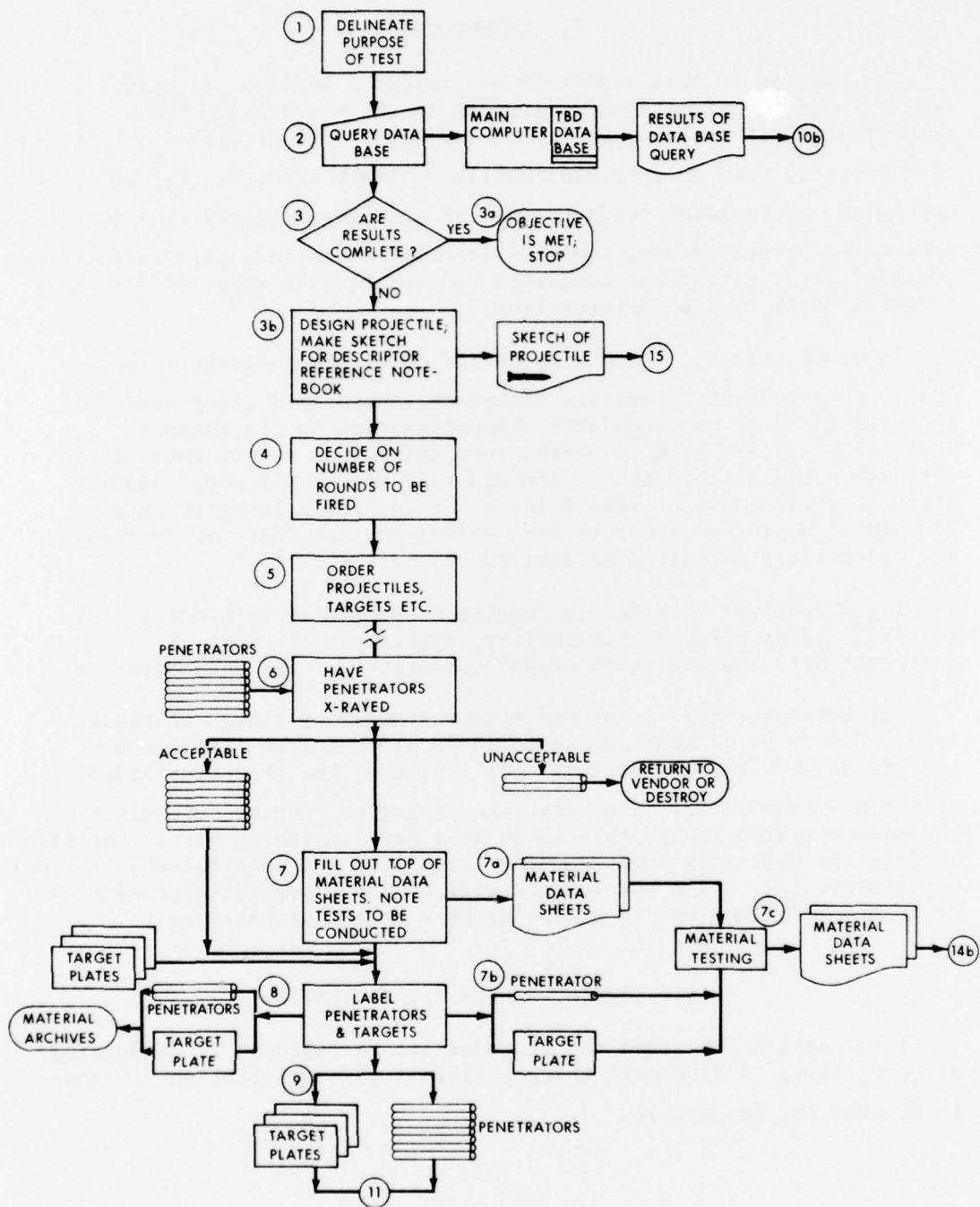


Figure 1a. Flow Chart of  $V_s$ ,  $V_r$  Test Procedure

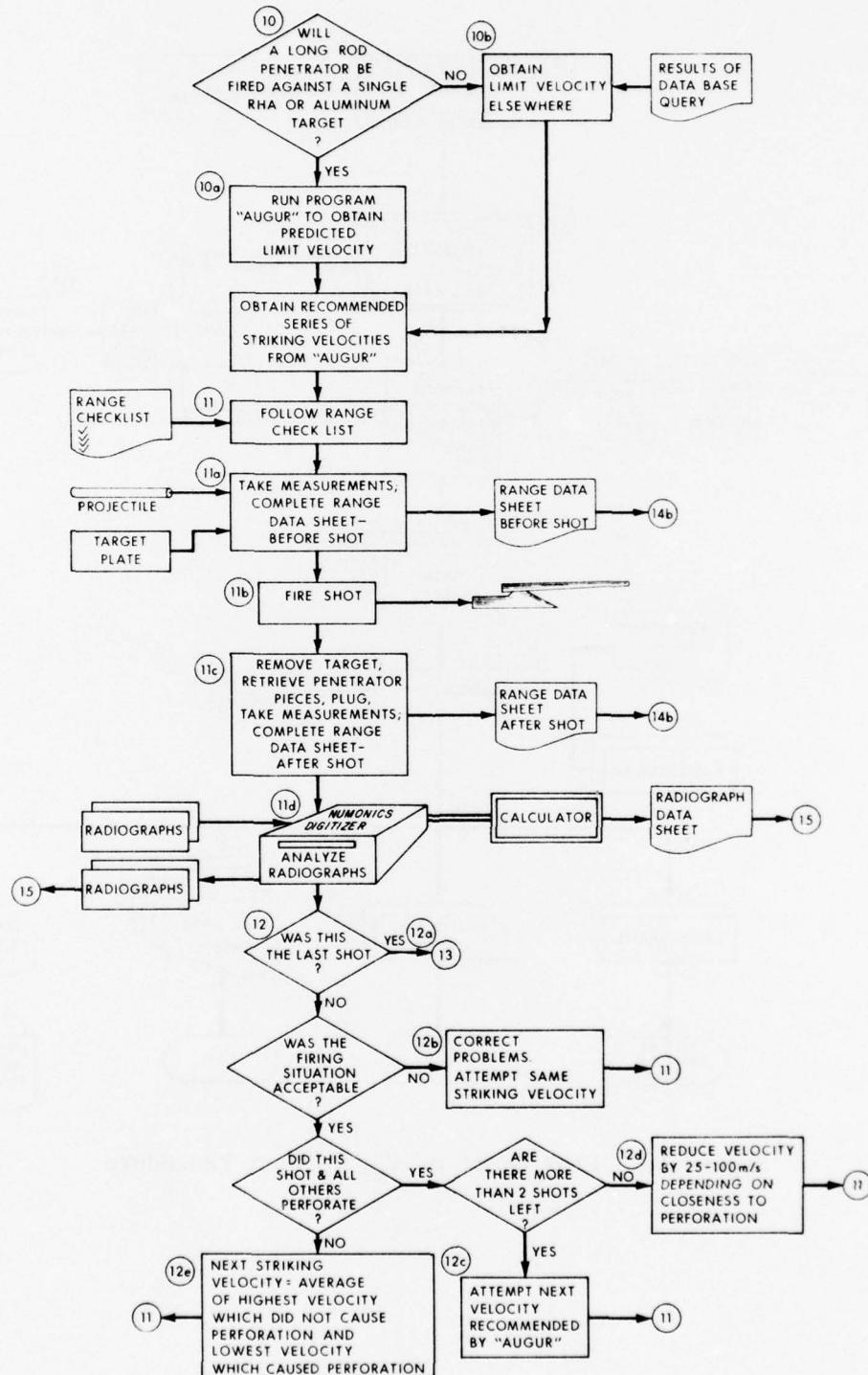


Figure 1b. Flow Chart of  $V_s$ ,  $V_r$  Test Procedure

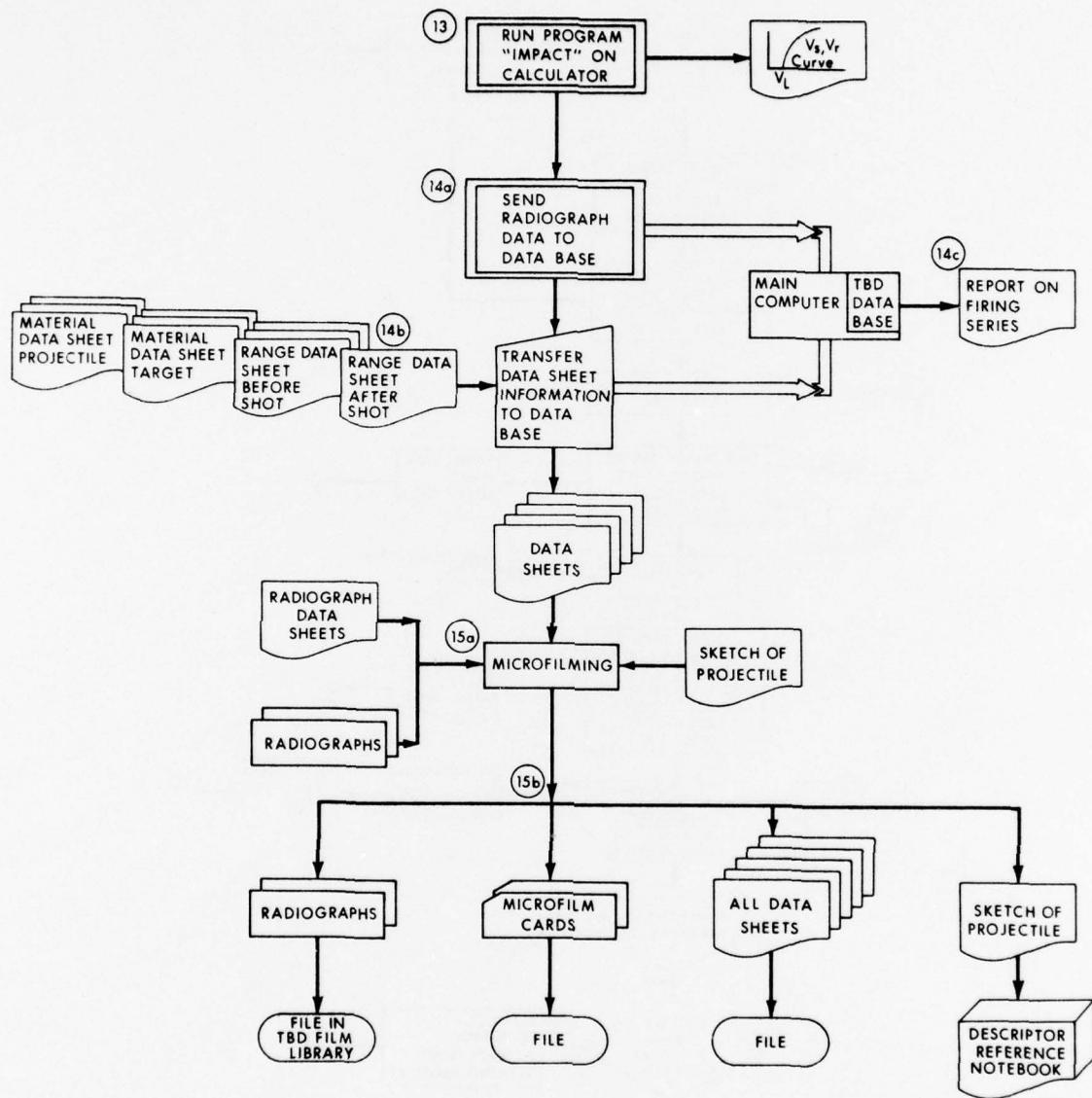


Figure 1c. Flow Chart of  $V_s$ ,  $V_r$  Test Procedure

1. Delineate the purpose of the test.

2. Query the TBD Penetrator Data Base<sup>1</sup> to determine what information is available for this test situation (see Appendix A for an example of such a query).

3.a. If the data base query provides complete results for the proposed test situation the objective is met and there is no need to conduct the test. (Hopefully, this is a valid possibility in the near future when the details of every firing series conducted after 1977 will have been routinely stored in the data base.)

3.b. If the data base query provides incomplete results, design a projectile, make a detailed dimensioned sketch of it to be included in the Descriptor Reference Notebook\* and assign the next consecutive Descriptor Reference # to it.

4. Decide on the number of rounds to be fired - always at least four. For long rod penetrators our experience suggests the frequent suitability of a six-shot  $V_s$ ,  $V_r$  test (i.e., six "good" shots), which we regard as providing a high level of confidence in the limit velocity estimate and in the entire  $V_s$ ,  $V_r$  curve for a broad range of situations\*\*. In general, the number of shots to be fired will be situation dependent and, except that there should always be at least four shots, this number will be left to the discretion of the project engineer.

5. Order sufficient projectiles, targets and other experimental apparatus so there will be reasonable assurance of obtaining that number of "good" rounds. (Rounds used in  $V_s$ ,  $V_r$  testing are expected to be essentially without yaw; we require that total yaw not exceed  $2\frac{1}{2}^\circ$  in order for the round to be used in the derivation of a limit velocity and  $V_s$ ,  $V_r$  curve).

6. Have x-rays taken of all penetrators (especially those of complex design) so that significant flaws in material or fabrication may be detected before firing and penetrators replaced as appropriate. (Such procedure further provides the possibility of correlating aspects of the radiographic image with subsequent ballistic behavior.)

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<sup>1</sup>B. Ringers, "Establishment of a KE Penetrator Data Base", to appear if this recommended standardization procedure is, indeed, adopted.

\*Located in TBD Film Library (see footnote, page 17).

\*\*Note the comparison between the predicted  $V_s$ ,  $V_r$  curves and  $V_l$ 's and the derived  $V_s$ ,  $V_r$  curves and  $V_l$ 's based on actual firings for four firing series noted in John P. Lambert, "The Terminal Ballistics of Certain 65 Gram Long Rod Penetrators Impacting Steel Armor Plate", Appendix E, to appear.

7.a. Fill out the top of the Material Data Sheets\* (identification section) for the penetrator and target(s) and note which material tests are to be conducted.

7.b. Send labeled samples of the penetrator and target(s) and the associated Material Data Sheets to Material Testing\*\*.

7.c. Material Testing should conduct the material tests requested and return the completed Material Data Sheets. (See Step 14b for further processing of these data sheets).

8. Send two labeled samples of the penetrator and one labeled sample of each unique target plate to a Materials Archives. These should be available for future scrutiny and it is imperative that they not be used in the firing program.

9. The remaining penetrators and target plates are to be used in the firing program. (See Step 11 for a continuation of their progress.)

10.a. If the impact situation is a long rod penetrator impacting a single rolled homogeneous armor (RHA) or aluminum (Al) target, use the program "Augur" (listed in Appendix F) to obtain a predicted limit velocity and a recommended series of striking velocities (and the anticipated corresponding residual velocities) for all but the last two shots. (For a detailed discussion of the striking velocity determination recommended for  $V_s$ ,  $V_r$  testing and used in "Augur", see Appendix B).

10.b. If the impact situation is other than that described in 10a, a predicted limit velocity must be obtained elsewhere\*\*\*, possibly extrapolated from the data base query. The program "Augur" is then used only to obtain a recommended series of striking velocities for all but the last two shots\*\*\*\*.

11. For each shot in a firing series, systematically follow a range checklist to insure accurate requisition of necessary data. (A proposed checklist for the BRL Terminal Ballistics Division Ranges 110E and G is provided in Appendix E as an example.) We assume that full radiographic

---

\*C.f., Section III for a copy of this and other data sheets.

\*\*Material Testing is presently the mission of the Solid Mechanics Branch, Terminal Ballistics Division, BRL.

\*\*\*Generalizations of the formulations given in Appendix B to cover other firing situations should be readily developed when the data base can provide sufficient empirical data.

\*\*\*\*The anticipated residual velocities obtained will probably be meaningless until the formulation \*\*\* is developed.

coverage is available and will be used to determine pre-impact and post-perforation penetrator characteristics; for a description of the standard multi-flash x-ray system, see BRL Technical Note 1634<sup>2</sup>.

The following tasks must be an integral part of any range procedure for conducting  $V_s$ ,  $V_r$  tests:

a. Before the shot is fired take the necessary projectile and target measurements and complete the Range Data Sheet - Before Shot (see Step 14b for further processing of this data sheet).

b. Fire shot.

c. After the shot is fired, remove the target and retrieve the principal penetrator pieces and plug; take appropriate measurements and record them on the Range Data Sheet - After Shot. (See Step 14b for further processing of this data sheet.)

d. Analyze the radiographs using a Numonics Digitizer in tandem with a calculator (which can also communicate with the main computer). The necessary coordinates of the penetrator pieces (and plug) are digitized according to the procedure described in BRL Memorandum Report 2264<sup>3</sup>. Incorporated within the digitizer will be a program which is a modification of a FORTRAN program written by A. L. Arbuckle<sup>3</sup>. This program calculates striking and residual velocities, striking yaw, residual yaw rate, residual masses and cone and phase angles\*. These calculated parameters are automatically sent to the calculator which then produces the Radiograph Data Sheet and retains the information which will later be transmitted to the main computer.

12.a. If this is the last shot in a series proceed with step 13.

12.b. If some aspect of the firing situation was unacceptable (e.g., the yaw was too high, the quality of radiographs prevented accurate analysis, the striking velocity was not close to that intended) and there is sufficient firing apparatus remaining to fire another shot, correct the problems encountered with this shot and, attempting the same striking velocity, continue at the beginning of Step 11.

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<sup>2</sup>C. Grabarek and L. Herr, "X-ray Multi-Flash System for Measurement of Projectile Performance at the Target", BRLTN 1634, September 1966 (AD 3377657).

<sup>3</sup>A. L. Arbuckle, E. L. Herr, A. J. Ricchiazzi, "A Computerized Method of Obtaining Behind-the Target Data From Orthogonal Flash Radiographs", BRLMR 2264, January 1973.

\*See definitions in Section IV.

12.c. If this shot (and all previous shots) perforated and there are more than two shots left, attempt the next striking velocity recommended by "Augur" and continue at the beginning of Step 11.

12.d. If this shot (and all previous shots) perforated and there are only one or two shots left, decrease the striking velocity by 25 - 100 m/s, depending on the "closeness" to non-perforation\* of the previous shot. Continue at the beginning of Step 11.

12.e. If the shot did not perforate or the shot perforated and at least one previous shot did not perforate, let the next striking velocity be the average of the lowest striking velocity which caused perforation and the highest striking velocity which resulted in non-perforation\*\*. Continue at the beginning of Step 11.

13. Use the  $V_s$ ,  $V_r$  data, as determined by radiographic analysis (Step 11d) and the BASIC program "Impact" (listed in Appendix G) to extract the "standard"  $V_s$ ,  $V_r$  curve and  $V_\ell$ . (The procedure used in "Impact" to generate a standard  $V_s$ ,  $V_r$  curve and standard  $V_\ell$  estimate is described in BRL Report 1852<sup>4</sup>.

14.a. Prompt the calculator to send the radiograph data stored within it to the TBD Penetrator Data Base<sup>1</sup>.

14.b. Transfer the data from the Material Data Sheets, the Range Data Sheet - Before Shot, and the Range Data Sheet - After Shot to the TBD Penetrator Data Base for each round in a series<sup>1</sup>.

14.c. A complete report on this firing series will subsequently be generated by a computer program (to be written in FORTRAN and reside on the main computer).

15.a. Have the radiographs, all the data sheets, and the sketch of the projectile, microfilmed. This involves reproducing the radiographs, data sheets and sketch on 16mm film. The processed film is then stored on microfilm cards which are filed for future reference; the radiographs, data sheets and sketch are returned.

\*Such "closeness" should be estimated from either the measured residual velocity or the target plate center hole size. The center hole diameter reduces and approaches the diameter of the penetrator as the striking velocity approaches the limit velocity.

\*\*If the striking velocities for two successive shots are determined this way and both perforate, attempt the highest striking velocity for which there was non-perforation again.

<sup>4</sup>J. P. Lambert and G. H. Jonas, "Towards Standardization in Terminal Ballistics Testing: Velocity Representation", BRL Report 1852, January 1976 (AD A021289).

15.b. Store the radiographs in the TBD Film Library\*, file the data sheets, and add the sketch to the Descriptor Reference Notebook. (The radiographs and data sheets are kept for five years after which time they are destroyed, their contents available and reproducible from the microfilm cards.)

\*The TBD Film Library is presently located in Bldg 309, Room 102. Access to it must be arranged with the Film Librarian.

### III. DATA SHEETS

Routine characterization of the  $V_s$ ,  $V_r$  test and documentation of basic information gathered in the test should be recorded on the following standard data sheets.

### MATERIAL DATA

Material Ref # \_\_\_\_\_

Material \_\_\_\_\_

Source \_\_\_\_\_

Lot # \_\_\_\_\_

Plate # or Bar # \_\_\_\_\_

Material Certification # \_\_\_\_\_ and Source \_\_\_\_\_

(if different from  
manufacturer)

<u>Property</u>	<u>Test Method</u>	<u>Date</u>	<u>Source</u>
-----------------	--------------------	-------------	---------------

- 1. Sample of same lot #.
- 2. Sample of similar material.
- 3. Nominal - handbook value.

#### Tension

Yield Stress (MPa) \_\_\_\_\_

Ultimate Stress (MPa) \_\_\_\_\_

Strain at the Ultimate Stress \_\_\_\_\_

Strain to Failure \_\_\_\_\_

Strain Rate ( $s^{-1}$ ) \_\_\_\_\_

#### Compression

Yield Stress (MPa) \_\_\_\_\_

Ultimate Stress (MPa) \_\_\_\_\_

Strain at the Ultimate Stress \_\_\_\_\_

Strain Rate ( $s^{-1}$ ) \_\_\_\_\_

Elastic Modulus (GPa) \_\_\_\_\_

Poisson's Ratio \_\_\_\_\_

Shear Modulus (GPa) \_\_\_\_\_

Charpy (dyne-cm) \_\_\_\_\_

Hugoniot Elastic Limit (MPa) \_\_\_\_\_

COMMENTS: \_\_\_\_\_

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RANGE DATA SHEET - BEFORE SHOT

Project Engineer \_\_\_\_\_ Comments: \_\_\_\_\_  
 Project ID \_\_\_\_\_  
 Range \_\_\_\_\_  
 Gun Caliber Smooth Bore Rifling \_\_\_\_\_  
 Date (month/day/yr) \_\_\_\_\_  
 Round # \_\_\_\_\_ Name \_\_\_\_\_ Series \_\_\_\_\_  
 Type: Experimental \_\_\_\_\_ Fielded \_\_\_\_\_  
 Sabot: Discarding \_\_\_\_\_ Non-Discarding \_\_\_\_\_ None \_\_\_\_\_  
 Descriptor Reference # \_\_\_\_\_  
 (detailed drawing and description including stabilizer if applicable)

Projectile

Total Mass (g) _____	Launch Mass (g) _____
Total Length (cm) _____	Powder Type _____
Maximum Diameter (excluding stabilizer) (cm) _____	Powder Mass (g) _____

Penetrator

Nose Shape \_\_\_\_\_  
 Total Length (cm) \_\_\_\_\_  
 Maximum Diameter (cm) \_\_\_\_\_

<u>Projectile Part</u>	<u>Mass</u> (g)	<u>Material</u>	<u>Ref. #</u>	<u>Hardness</u> Value	<u>Density</u> Test (g/cc)
------------------------	--------------------	-----------------	---------------	--------------------------	----------------------------------

A. Penetrator

Penetrator Parts	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

B. Aerodynamic  
Shell

\_\_\_\_\_

C. Stabilizer

Rate of Spin (rps) \_\_\_\_\_ (if spin stabilized)

Target Plate 1

Material \_\_\_\_\_ Ref# \_\_\_\_\_  
 Incidence Angle (deg) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Thickness (cm) \_\_\_\_\_  
 Hardness - Value \_\_\_\_\_  
     - Test \_\_\_\_\_  
 Density (g/cc) \_\_\_\_\_  
 Type: Rect Cir  
 Lgth/Dia (cm) \_\_\_\_\_  
 Width (cm) \_\_\_\_\_

Target Plate 2

Material \_\_\_\_\_ Ref# \_\_\_\_\_  
 Incidence Angle (deg) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Thickness (cm) \_\_\_\_\_  
 Hardness - Value \_\_\_\_\_  
     - Test \_\_\_\_\_  
 Density (g/cc) \_\_\_\_\_  
 Type: Rect Cir  
 Lgth/Dia (cm) \_\_\_\_\_  
 Width (cm) \_\_\_\_\_  
 Spacing between plates 1 and  
2 (cm) \_\_\_\_\_

Target Plate 3

Material \_\_\_\_\_ Ref# \_\_\_\_\_  
 Incidence Angle (deg) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Thickness (cm) \_\_\_\_\_  
 Hardness - Value \_\_\_\_\_  
     - Test \_\_\_\_\_  
 Density (g/cc) \_\_\_\_\_  
 Type: Rect Cir  
 Lgth/Dia (cm) \_\_\_\_\_  
 Width (cm) \_\_\_\_\_  
 Spacing between plates 2 and  
3 (cm) \_\_\_\_\_

## RANGE DATA SHEET - AFTER SHOT

Project ID \_\_\_\_\_ Comments: \_\_\_\_\_  
 Round # \_\_\_\_\_ Series \_\_\_\_\_

<u>Recovered Penetrator</u>	<u>Piece 1</u>	<u>Piece 2</u>	<u>Piece 3</u>	
Residual Mass (g)	_____	_____	_____	_____
Residual Length (cm)	_____	_____	_____	_____

Plug  
 Mass (g) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_  
 Diameter (cm) \_\_\_\_\_

Target Plate 1  
 Mass (g) \_\_\_\_\_

Entrance Hole  
 Minimum distance from hole to plate edge (cm) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_

Perforation? Yes \_\_\_\_\_ No \_\_\_\_\_

Center Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_  
 Penetration depth (cm) \_\_\_\_\_  
 Bulge extent, from rear plate surface (cm) \_\_\_\_\_

Exit Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_ Back surface fracture? Yes \_\_\_\_\_ No \_\_\_\_\_

Target Plate 2  
 Mass (g) \_\_\_\_\_

Entrance Hole  
 Minimum distance from hole to plate edge (cm) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_

Perforation? Yes \_\_\_\_\_ No \_\_\_\_\_

Center Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_  
 Penetration depth (cm) \_\_\_\_\_  
 Bulge extent, from rear plate surface (cm) \_\_\_\_\_

Exit Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_ Back surface fracture? Yes \_\_\_\_\_ No \_\_\_\_\_

Target Plate 3  
 Mass (g) \_\_\_\_\_

Entrance Hole  
 Minimum distance from hole to plate edge (cm) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_

Perforation? Yes \_\_\_\_\_ No \_\_\_\_\_

Center Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_  
 Penetration depth (cm) \_\_\_\_\_  
 Bulge extent, from rear plate surface (cm) \_\_\_\_\_

Exit Hole  
 Length (cm) \_\_\_\_\_ Width (cm) \_\_\_\_\_ Back surface fracture? Yes \_\_\_\_\_ No \_\_\_\_\_

### RADIOGRAPH DATA

Project ID \_\_\_\_\_ Comments: \_\_\_\_\_  
 Range \_\_\_\_\_  
 Gun Caliber \_\_\_\_\_  
 Date (month/day/yr) \_\_\_\_\_  
 Round # \_\_\_\_\_ Series \_\_\_\_\_  
 File # \_\_\_\_\_

<u>Projectile</u>	<u>Plug</u> (if applicable)
Striking Velocity (m/s)	Velocity (m/s)
Striking Yaw - Vertical (deg) (up: +, down: -) ( $\alpha$ )	Mass (g)
Striking Yaw - Horizontal (deg) (right: +, left: -) ( $\beta$ )	Length (cm)
Total Yaw - ( $\delta$ ) (deg)	Diameter (cm)
	Trajectory -
	Cone Angle ( $\lambda$ ) (deg)
	Phase Angle ( $\phi$ ) (deg)

### Penetrator, Residual

<u>Plate 1</u>	<u>Piece 1</u>	<u>Piece 2</u>	<u>Piece 3</u>
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle ( $\lambda$ ) (deg)	_____	_____	_____
Phase Angle ( $\phi$ ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____
<u>Plate 2</u>			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle ( $\lambda$ ) (deg)	_____	_____	_____
Phase Angle ( $\phi$ ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____
<u>Plate 3</u>			
Velocity (m/s)	_____	_____	_____
Mass (g)	_____	_____	_____
Length (cm)	_____	_____	_____
Trajectory -	_____	_____	_____
Cone Angle ( $\lambda$ ) (deg)	_____	_____	_____
Phase Angle ( $\phi$ ) (deg)	_____	_____	_____
Vertical Yaw Rate (rev/sec)	_____	_____	_____

#### IV. DEFINITIONS OF RELEVANT BALLISTIC AND DATA BASE TERMINOLOGY

1.  $V_s$ ,  $V_r$  Test - the firing of a number of nominally identical penetrators into as many nominally identical targets with all controlled phenomena except striking velocity being nominally invariant (i.e., a fixed "projectile-target situation"); penetrator striking and residual velocities from each shot are measured and a collection of data points ( $V_s$ ,  $V_r$ ) is thereby generated.

The primary purpose of conducting a  $V_s$ ,  $V_r$  test is to analyze the dependence of residual velocity on striking velocity (including limit velocity determination) for a specified projectile-target situation. The radiographic coverage needed for velocity measurement provides relatively easy access to further penetration mechanics analysis: frequent additional objectives in  $V_s$ ,  $V_r$  testing involve, for instance, study of the dependence on striking velocity of various residual effects (e.g., residual penetrator mass; the shape, mass, and velocity of a plug or of other fragment debris).

2. Limit Velocity ( $V_\ell$ ) - value determined from a set of  $V_s$ ,  $V_r$  data (as generated in a  $V_s$ ,  $V_r$  test) using the computational algorithm described in BRLR 1852 (AD 20376);  $V_\ell$  is one of a triple of values ( $a$ ,  $p$ ,  $V_\ell$ ) which minimizes the root mean square error when the form

$$V_r = \begin{cases} 0, & 0 \leq V_s \leq V_\ell \\ a(V_s^p - V_\ell^p)^{1/p}, & V_s > V_\ell \end{cases} \text{ is applied to the given } V_s, V_r \text{ data set.}$$

Note: the idealized physical notion abstracted to suggest the above form is that of an absolutely invariant projectile-target situation for which each striking velocity can yield one and only one residual velocity (and then  $V_\ell = \max\{V_s : V_r = 0\} = \inf\{V_s : V_r > 0\}$ ).

3. Material Ref # - unique number assigned to each penetrator and target material as a cross reference between Range Data and Material Data Sheets.
4. Material - generic name of material, including specification (i.e. S7 Tool Steel, AISI 1030 Steel).
5. Source - Manufacturer of plate or bar of material.

6. Lot # - unique number assigned by manufacturer to identify the material and associated processing for a group of plates or bars, i.e., two plates from the same lot should be nominally identical.
7. Plate # - unique number assigned to a 6' x 6' or 6' x 12' plate to identify its relation to the other plates in a lot. This may be further subdivided into target plates by the experimenter.
8. Material Certification # - unique number identifying the material certificate which describes the chemical composition and processing history of the material.
9. Name - expression assigned to a group of projectiles of nominally identical design (e.g., L15, GAU 8, etc.).
10. Series - unique number assigned to a group of rounds within a project; typically used to classify a group of related rounds, e.g., those within a single V<sub>s</sub>, V<sub>r</sub> test sequence.
11. Descriptor Reference # - unique number assigned sequentially to denote location of drawing and description pertaining to a round in the Descriptor Reference Notebook.
12. Projectile - aggregate of penetrator, aerodynamic shell, and stabilizer, (also sabot, if nondiscarding) i.e., that part of the launch mass which remains intact during flight and is expected to impact the target as a unit.
13. Launch Mass - mass of the projectile, sabot, pusher plate(s), and obturator.
14. Penetrator - that part of the projectile which is responsible for damaging the target. It may contain the following parts:
  - a. Armor-piercing Cap - piece fitted to front of penetrator to preserve body from brunt of initial impact, usually made of tough, hard, shock-absorbing material.
  - b. Body or core - principal part of penetrator responsible for damaging target.
  - c. Sheath - material which partially surrounds core.
  - d. Composite Body - body divided into forebody and aftbody.
15. Aerodynamic Shell - outer part of projectile to aid in flight only, usually made of light material like aluminum.

16. Stabilizer - means of maintaining stability during flight so that projectile strikes nose first (e.g., fins, flare, spin).
17. Incidence Angle (or Obliquity) ( $\theta$ ) - angle between the penetrator line of fire (path of the center of gravity) and the normal to the target plane.
18. Spacing between plates - orthogonal distance between plates.
19. Plug - a major fragment which may be punched out from the target, usually at striking velocities near the limit velocity. A plug is of roughly cylindrical shape having diameter at least as large as that of the penetrator and height (or length) no greater than the target plate thickness; front and rear ends tend to be convex and concave respectively and the lateral surface shows strong indication of shear.
20. Entrance Hole - hole made in the front surface of the target (in Figure 2., length =  $L_1$ , width =  $W_1$ ).
21. Min. distance from hole to plate edge - The minimal distance, on the front target surface plane, from the hole perimeter to the edge of the target plate (in Figure 2., min. dist. =  $a$ ).
22. Perforation - passage of a penetrator completely through a target. In terms of velocity, we say there is perforation if and only if  $V_r > 0$ .
23. Center Hole - smallest hole in the target on neither front nor rear surface (perforation only) (in Figure 2., length =  $L_2$ , width =  $W_2$ ).
24. Exit Hole - hole made in the rear surface of the target (perforation only). (in Figure 2., length =  $L_3$ , width =  $W_3$ ).
25. Penetration Depth - target hole depth measured from the front target surface plane (nonperforation only). (see Figure 3).
26. Bulge extent from rear plate surface - maximum target material displacement from rear target surface plane (nonperforation only). (see Figure 3).
27. File # - location number of radiographs in TBD Film Library.
28. Striking Velocity ( $V_s$ ) - velocity (really, speed) of penetrator at impact; determined from the position, time history of before-target radiographic images.

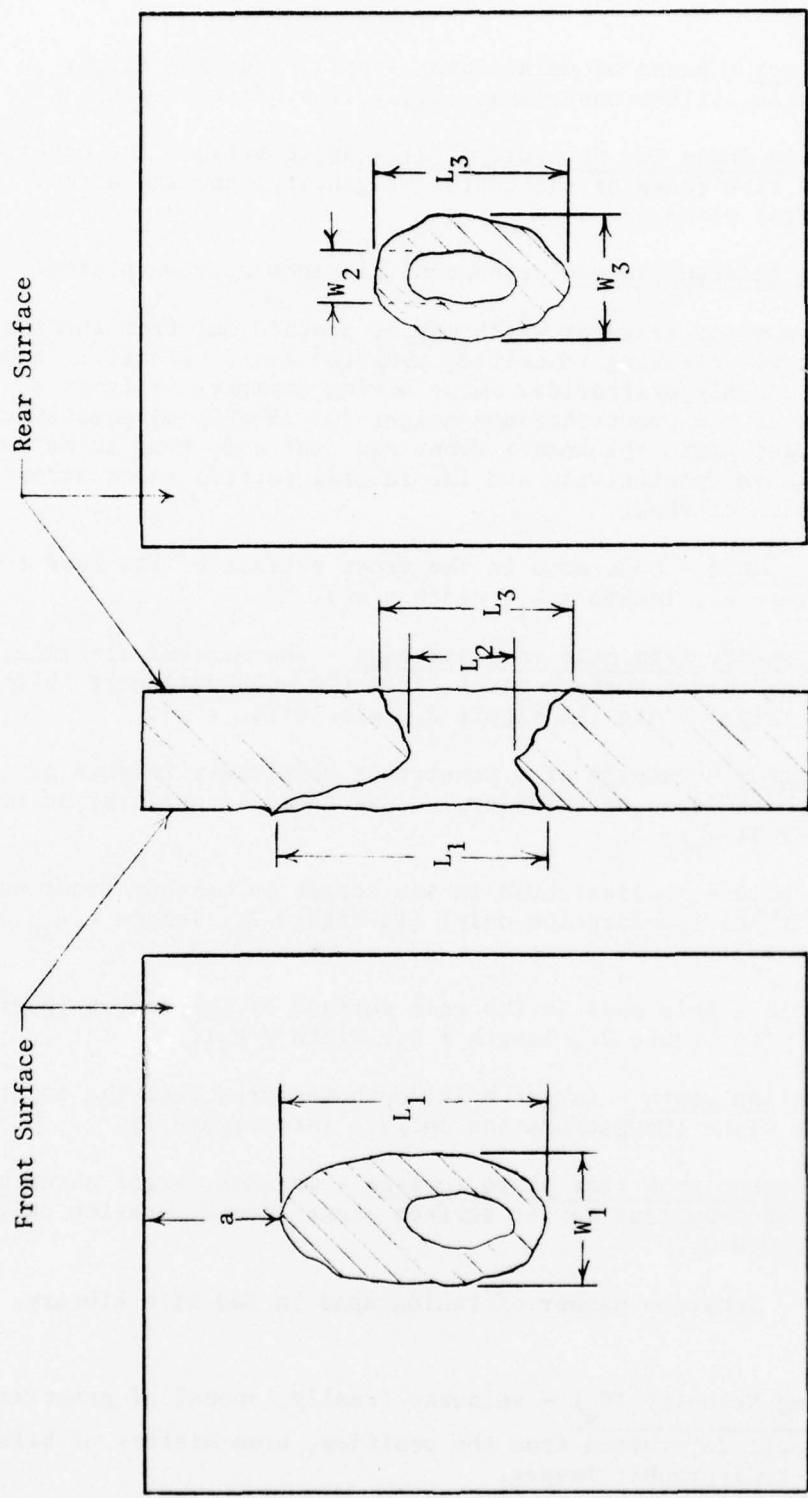
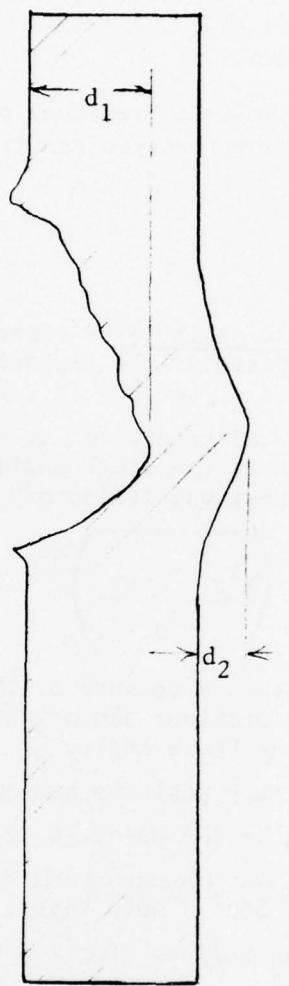


Figure 2. Perforated Target Plate: Front and Rear Surfaces and Sectioned Side View



$d_1$ : Penetration depth

$d_2$ : Bulge extent from rear plate surface

Figure 3. Non-Perforated Target Plate: Sectioned Side View

The following geometric setting will be used in describing items 29 and 30 (Figures 4 and 5). Consider a coordinate system in which the origin is on the line of fire at a point midway through the target plate, the z-axis coincides with the line of fire, and the x and y axes are respectively horizontal and vertical with respect to the test set-up. (In the context of usual experimental procedure, this means that the x-axis is parallel to and midway between the front and rear target surfaces and that the y-axis makes with these surfaces an angle equal to the obliquity.)

Note: Wherever used, the term "residual penetrator" will refer to the major (largest) post-perforation penetrator remnant,

29. Cone Angle ( $\lambda$ ) and Phase Angle ( $\phi$ ) - these are behind-target characteristics descriptive of the trajectory of the residual penetrator (see Figure 4). Let  $P = (x_o, y_o, z_o)$  be the center of gravity of the residual penetrator at some point behind the target. The Cone Angle is the acute angle between the line of fire (z-axis) and the residual trajectory (line from the origin through P):

$$\lambda = \tan^{-1} \left( \sqrt{\frac{x_o^2 + y_o^2}{z_o^2}} \right)$$

The Cone Angle is thus a measure of the deflection in trajectory caused by perforation; the orientation of this deflection will be provided by the Phase Angle.

Let  $y_1$  be an arbitrary positive number; let  $r$  be the point  $(0, y_1, z_o)$  and let  $q$  be the point  $(0, 0, z_o)$ . Then the Phase Angle is  $\phi = \angle rqp$  (measured clockwise as perceived from the origin);  $0^\circ \leq \phi < 360^\circ$ . Note that  $\phi$  is not defined if  $\lambda = 0^\circ$ .

We can specify  $\phi$  as follows (for  $\lambda \neq 0^\circ$ ):

$$(i) \text{ If } y_o = 0, \text{ let } \phi = \begin{cases} 90^\circ & \text{if } x_o > 0 \\ 270^\circ & \text{if } x_o < 0 \end{cases}$$

$$(ii) \text{ If } y_o \neq 0, \text{ let } \psi = \tan^{-1} \left( \frac{x_o}{y_o} \right), \quad -90^\circ < \psi < 90^\circ,$$

$$\text{and } \phi = \begin{cases} \psi + 180^\circ & \text{if } y_o < 0 \\ \psi & \text{if } y_o > 0 \text{ and } x_o \geq 0 \\ \psi + 360^\circ & \text{if } y_o > 0 \text{ and } x_o < 0 \end{cases} .$$

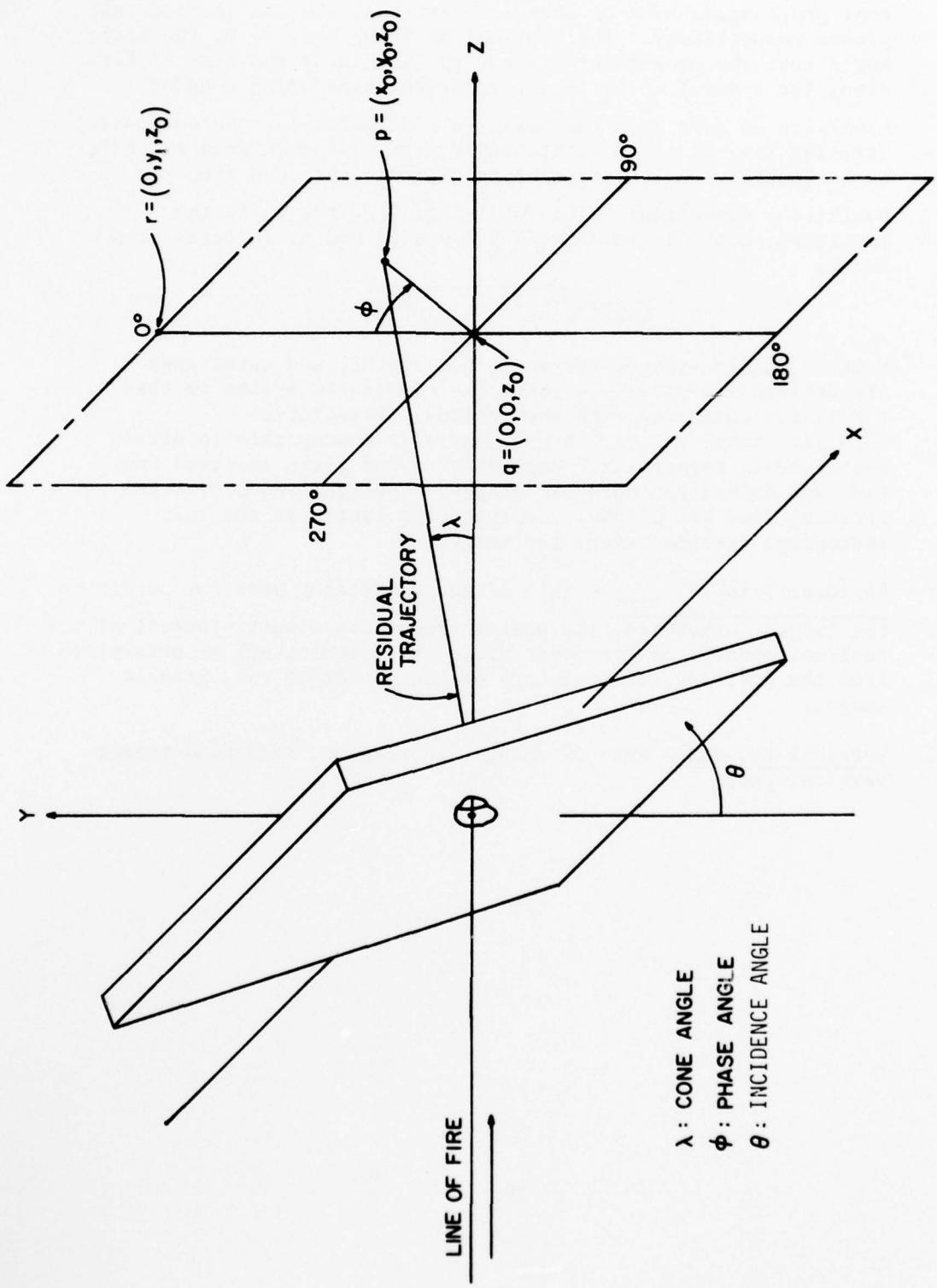


FIGURE 4. COORDINATE SYSTEM DEPICTING ANGLES  $\lambda$ ,  $\phi$ , AND  $\theta$ .

30. Striking Yaw: Vertical ( $\alpha$ ), Horizontal ( $\beta$ ), Total ( $\delta$ ) - (See Figure 5) for the penetrator at a point prior to impact, let  $A$  be the penetrator axis of symmetry; let  $A_1$  and  $A_2$  be the orthogonal projections of  $A$  on the  $y$ - $z$  (vertical) and  $x$ - $z$  (horizontal) planes respectively. The Vertical Striking Yaw,  $\alpha$ , is the acute angle from the penetrator trajectory (initially the line of fire along the  $z$  axis) to  $A_1$  (positive orientation being counter-clockwise as seen from the positive  $x$ -direction). The Horizontal Striking Yaw,  $\beta$ , is the acute angle from the penetrator trajectory to  $A_2$  (positive orientation being clockwise as seen from the positive  $y$  direction). The Total Striking Yaw,  $\delta$ , is the (positive) acute angle between the  $z$ -axis and  $A$ ; in terms of  $\alpha$  and  $\beta$ ,

$$\delta = \tan^{-1} \sqrt{\tan^2 \alpha + \tan^2 \beta}$$

Note i: behind-target vertical, horizontal, and total yaws are defined analogously - reset the coordinate system so that the  $z$ -axis coincides with the residual trajectory.

Note ii: total yaw,  $\delta$ , is not generally susceptible to direct measurement; rather its "components"  $\alpha$  and  $\beta$  are inferred from side and bottom radiographic images. Vertical and horizontal striking yaws are properly derived from images at the last radiograph station before the target.

31. Residual Velocity ( $V_r$ ) - zero if the penetrator does not perforate the target; otherwise, the post-perforation velocity (speed) of the residual penetrator (or other piece if so indicated) as determined from the position, time history of behind-target radiographic images.

32. Vertical Yaw Rate - Rate of change, in rev/sec, of behind-target vertical yaw.

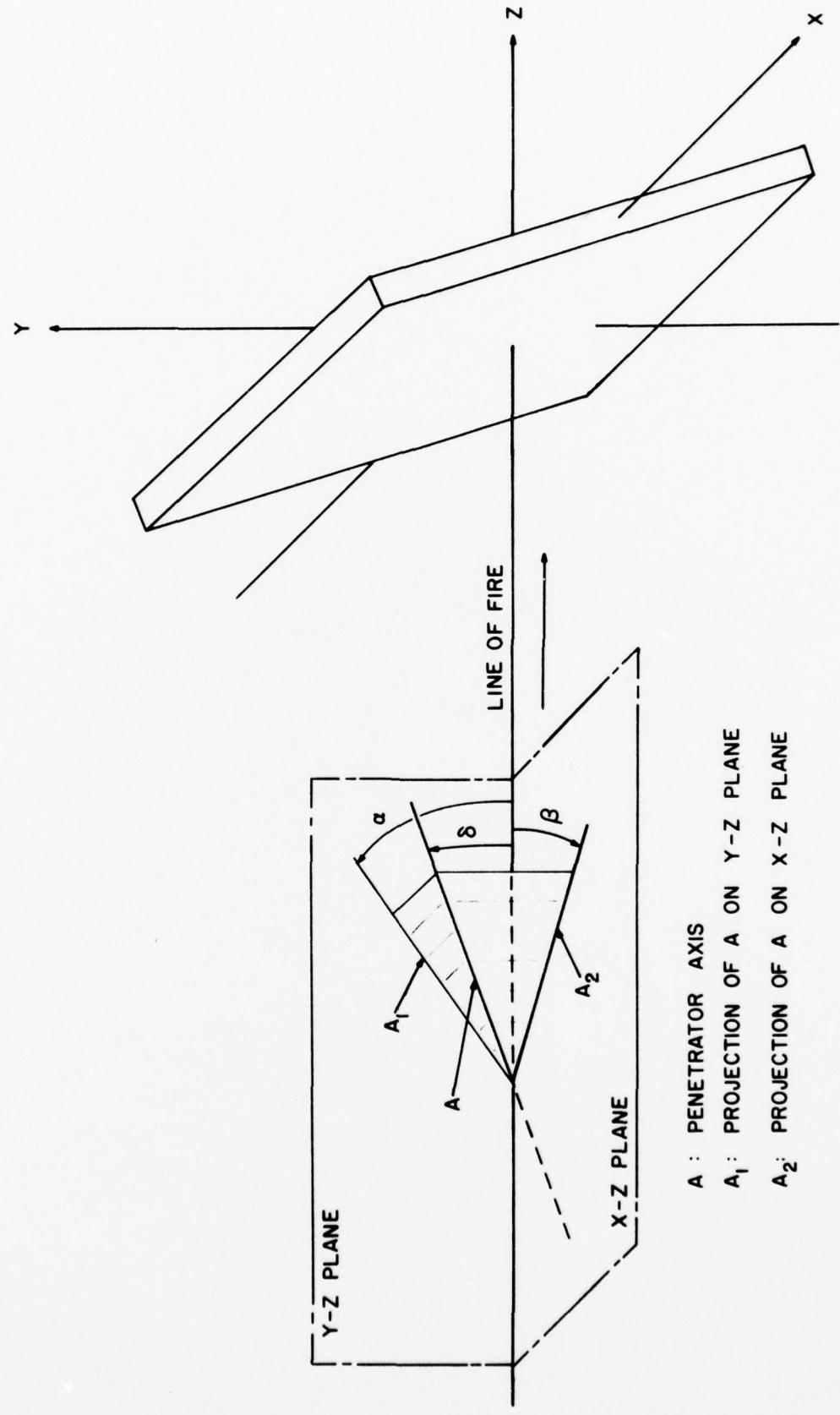


FIGURE 5. COORDINATE SYSTEM DEPICTING YAW ANGLES  $\alpha$ ,  $\beta$ , AND  $\delta$ .

## APPENDIX A

### Query to Data Base

The following is a somewhat elementary example illustrating possible use of the data base.

## APPENDIX A

Suppose you are interested in the performance of tungsten penetrators (65g, L/D of 10, hemispherical nose shape) against a double RIA target, 0.63cm (1/4") and 1.9cm (3/4") thick, spaced 8.26cm (3 1/4") apart at 60° obliquity. The following command to the data base<sup>1</sup> would produce the information available with the qualifications specified and in sorted order for easier analysis. Note: the asterisk is part of the instruction.

SORT AND PRINT: STRIKING VELOCITY, RESIDUAL VELOCITY 1, RESIDUAL VELOCITY 2, RESIDUAL MASS 1, RESIDUAL MASS 2  
FOR WITH PENETRATOR MATERIAL, TUNGSTEN AND  
PENETRATOR MASS, 65 AND  
L/D, 10 AND  
NOSE SHAPE, HEMISPHERICAL AND  
TARGET MATERIAL 1, RHA AND  
TARGET THICKNESS 1, .63 AND  
TARGET MATERIAL 2, RHA AND  
TARGET THICKNESS 2, 1.9 AND  
SPACING 1, 8.26 AND  
OBLIQUITY, 60 AND  
TOTAL YAW, FROM 0 to 2.5\*

A possible response to the query is:

NO. OF ITEMS IN QUERY RESPONSE = 50  
NO. OF ITEMS IN THE DATA BANK = 500  
PERCENTAGE OF RESPONSE/TOTAL DATA BASE = 10.00

STRIKING VELOCITY	RESIDUAL VELOCITY 1	RESIDUAL VELOCITY 2	RESIDUAL MASS 1	RESIDUAL MASS 2
1053 M/S	739 M/S	0 M/S	30.2 G	0.0 G
1500 M/S	1320 M/S	309 M/S	50.5 G	22.3 G
:	:	:	:	:

This query could also be stated more compactly in terms of the relative placement of the parameters in the data base as follows:

SORT AND PRINT: 134, 144, 162, 145, 163  
FOR WITH 23, 2 AND 22, 65 AND 198, 10 AND 19, 2 AND 59, 1 AND 63,  
.63 AND 70, 1 AND 74, 1.9 AND 81, 8.26 AND 61, 60 AND 137, FROM 0. TO  
2.5\*

The response should be the same.

APPENDIX B

Striking Velocity Allocation

## APPENDIX B

The purpose here is to specify a routine for generating the (intended) striking velocities to be used in a  $V_s$ ,  $V_r$  test.

In practice there will be a difference between the intended striking velocity (i.e., the velocity requested of the gun crew) and the actual realized striking velocity (i.e., the velocity measured, after the shot, from radiographic images) but this can generally be expected, on the basis of past experience, to be relatively small.

Suppose  $n (>4)$  to be the total number of rounds available for the test. For  $k = 1, 2, \dots, n$ , we denote by  $x'_k$  the intended striking velocity for the  $k$ th round, and by  $x_k$  and  $y_k$  respectively, the actual (measured) striking and residual velocities.

Let  $c$  be the initial estimate of limit velocity as calculated from the equations of Appendix D or the program "Augur" (which incorporates those equations) and is listed in Appendix F.\* Take  $x'_1$  to be the largest attainable (or desired) striking velocity.\*\*

Let  $n_o = n-2$ . Let  $q = (x'_1)^2 - c^2$ . For  $k = 1, 2, \dots, n_o$ ,

let  $b_k = \frac{n_o}{n_o - k}$  and let  $x''_k = \sqrt{c^2 + qb_k^2}$ .

This sequence of velocities ( $x''_1, x''_2, \dots, x''_{n_o}$ ) which has been constructed before any shots are fired will serve as a preliminary guide for the first  $n_o$  shots. The intended striking velocities ( $x'_k$ ) will follow this sequence (i.e.,  $x'_k = x''_k$ ) unless results significantly deviate from those anticipated. Motivation for use of this sequence is as follows: Consider the simplified partial model of the expected  $V_s$ ,  $V_r$  curve:

$y = \sqrt{x^2 - c^2}$  (where  $x, y, c$  have respectively replaced  $V_s, V_r, V_\ell$ );  
the relevant corresponding range of residual velocities is then the

\*In the case of multiple plate targets and for target materials other than RHA or Aluminum, the initial limit velocity estimate will need to be obtained elsewhere.

\*\*In most  $V_s$ ,  $V_r$  testing, a reasonably full  $V_s$ ,  $V_r$  curve is required and it is desirable to obtain residual velocities for a wide range of striking velocities - in such cases  $x'_1$  should be made as large as is feasible. Should interest be confined solely to limit velocity,  $x'_1$  might be given a smaller value, the only imperative being that the corresponding shot result in perforation.

interval  $[0, \sqrt{x'_1^2 - c^2}]$ . This interval is partitioned into  $n_o - 1$  equal parts and the  $x''_k$  are the  $n_o$  corresponding images of the partition points on the x axis.

Figure B-1 is intended to be illustrative of the procedure for a situation in which it is planned to fire six shots ( $n_o = 4$ ).

Now the general idea is to follow the  $x''_k$  sequence as a source of intended striking velocities until either a non-perforation ( $y_k = 0$ ) is reached or the sequence is exhausted. In most cases we expect this part of the procedure to provide for the major portion of the testing strategy. The remaining phase (involving possible departure from the  $x''_k$  distribution and allocation of the final two shots) is both tedious to describe and, infrequently we expect, open to the possibility of subjectivity.

A formal account of the procedure follows.  $x'_1$ , the intended striking velocity for the first shot, has already been selected. Fire the first shot\*. Take  $x'_2$ , the intended striking velocity for the second shot, to be  $x''_2$ . Fire the second shot. If the second shot perforates (and  $n > 4$ ), take  $x'_3$  (the intended striking velocity for the third shot) to be  $x''_3$  and fire the third shot. Continue in this manner until either a non-perforation is observed or the  $n_o$ th shot has been fired (with all shots having perforated). We have then two possibilities:

a. The preliminary sequence of shots has been exhausted with all shots resulting in perforation. Then  $y_1, y_2, \dots, y_{n_o}$  are all positive and  $x'_k = x''_k$  for  $k = 1, 2, \dots, n_o$ .

In this case, let  $x'_{n_o+1} = x_{n_o} - \delta$  where  $\delta$  is 25 m/s, 50 m/s, or 100 m/s at the discretion of the project engineer (as adjudged by the "closeness" to non-perforation of the previous shot).

Then, if  $y_{n_o+1} > 0$ , let  $x'_{n_o+2} = x_{n_o+1} - \delta$  where  $\delta$  is decided as before; if  $y_{n_o+1} = 0$ , let  $x'_n = 1/2 (x_{n_o} + x_{n_o+1})$ .

---

\*It is essential to our development that this shot perforate, and its doing so should be a nearly inevitable consequence of the selection of  $x'_1$ .

$c=x_4''$ : Predicted limit velocity.

$x_1'=x_1''$ : Selected maximum striking velocity of interest  
(or achievable).

$\{x_1'', x_2'', x_3'', x_4''\}$ : Preliminary striking velocity sequence.

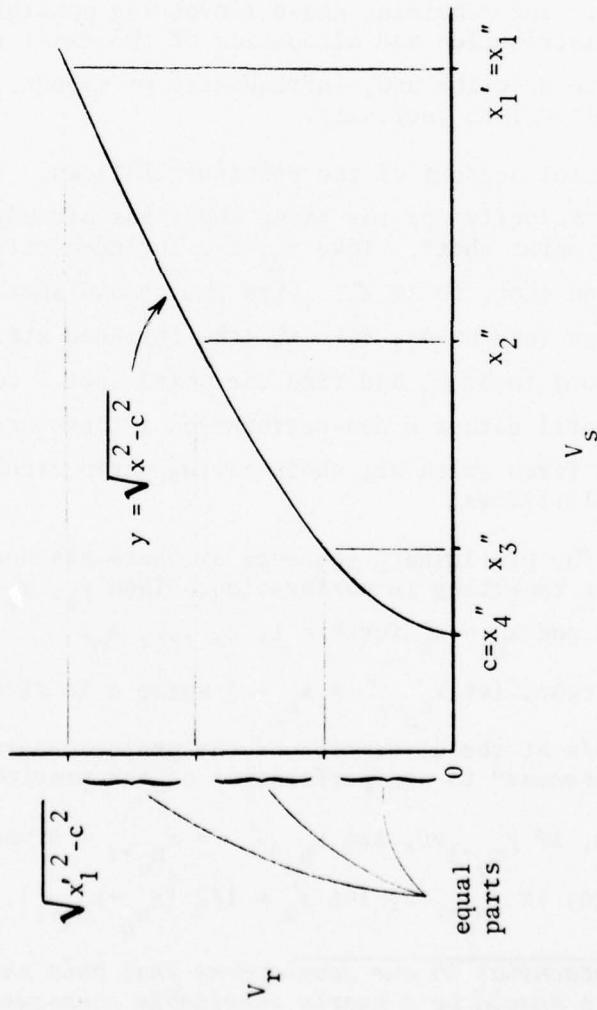


Figure B-1. Determining the Preliminary Sequence of Striking Velocities

b. the preliminary sequence must, at some point (say after the  $k_0$ th shot) be abandoned due to a non-perforation ( $y_1, y_2, \dots$ ,

$y_{k_0-1}$  are positive but  $y_{k_0} = 0$ ). In this case let

$$x'_{k_0+1} = \frac{1}{2} (x_{k_0} + x_{k_0-1}).$$

Then, for  $j = k_0 + 2$  to  $n$ , let  $x'_j$  be the average of the lowest striking velocity which resulted in perforation and the highest striking velocity which resulted in non-perforation. Continue adhering to this procedure unless two successive rounds perforate; in such event, and should there be rounds remaining, try to duplicate the velocity of the  $k_0$ th shot (i.e., use  $x_{k_0}$  as the next attempted velocity) and then, depending on whether this results in perforation or not, follow the general provisions of (a) or (b) for successive shots.

## APPENDIX C

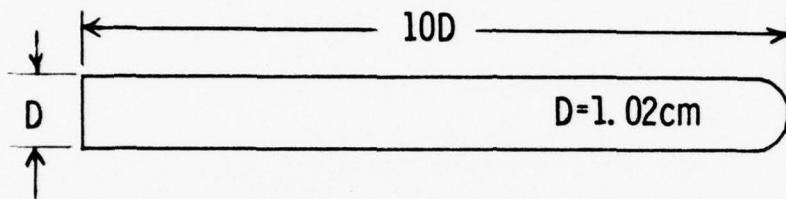
### Example: A Test Case Considered

The following is an example of the documentation generated in adhering to the tenets of this report during the course of a  $V_s$ ,  $V_r$  test.



1. Purpose of test: To derive a  $V_l$  estimate and  $V_s$ ,  $V_r$  curve for L/D of 10, nominal mass of 65 grams, VIMVAR\*-processed steel\*\* rods fired into 2.54cm RHA at 60° obliquity; and to compare performance with previous results for a similar situation involving rods not VIMVAR-processed. A seven shot  $V_s$ ,  $V_r$  test is planned.

2. Projectile illustration, with nominal dimensions:



VIMVAR-processed steel, finished hardness  $R_c$  55  
Nominal mass: 65 grams (average mass fired was 64.3 grams).

3. The equations of Appendix D provide the estimated parameter values:  $a = 0.88$ ,  $p = 3.4$ , and  $V_l = 1292$ ; the corresponding predicted  $V_s$ ,  $V_r$  curve is in Figure C-1. (In practice we use the BASIC program "Augur", which incorporates the equations of Appendix D and supplies graphic capability.)

4. 1800 m/s is regarded as a reasonable maximum velocity for the experimental set-up at hand, and from the equations of Appendix B we derive the preliminary sequence of five (intended) striking velocities: 1800, 1598, 1436, 1330, and 1292. Attempting to achieve (approximately) these velocities (in the indicated order), five rounds were fired and each resulted in perforation; actual striking velocities were measured to be respectively 1800, 1647, 1489, 1360, and 1282. For the sixth shot it was then decided to attempt a velocity of 1232 m/s, a drop of 50 m/s from the (actual) fifth striking velocity; the actual striking velocity obtained was 1227 m/s and there was perforation. For the seventh (and final) shot we then opted for a velocity reduction of 25 m/s, which was exactly realized - the seventh striking velocity was 1202 m/s and there was no perforation.

\*Vacuum induction melt, vacuum arc remelt.

\*\*Which, but for the lack of molybdenum as an alloying element, would have been AISI S7 tool steel.

Prediction of Limit Velocity and  $V_s$ ,  $V_r$  Curve for Steel Rods Impacting RHA

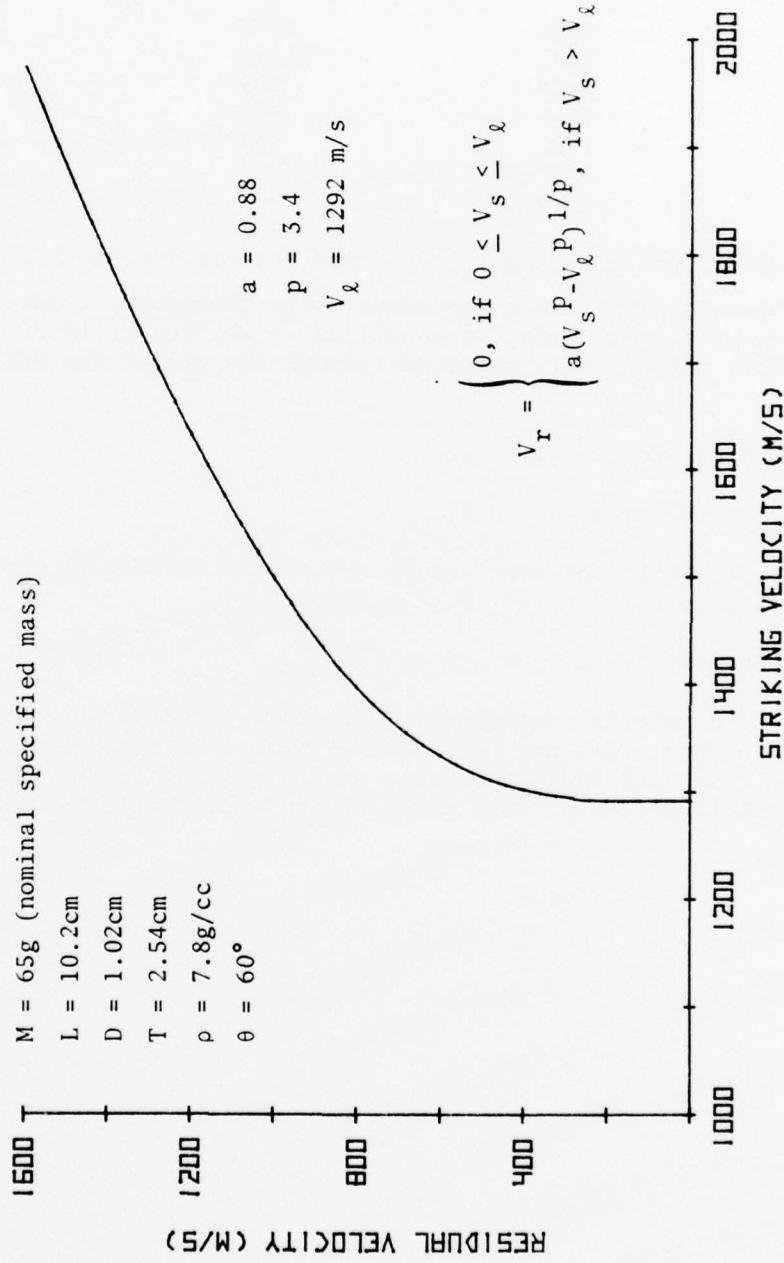


Figure C-1. Predicted  $V_\ell$  and  $V_s$ ,  $V_r$  Curve

5. The  $V_s$ ,  $V_r$  data for these shots, as determined from radiographs, is:

$\underline{V_s}$	$\underline{V_r}$
1800	1285
1647	1145
1489	903
1360	769
1282	510
1227	203
1202	0

Figure C-2 provides the  $V_s$ ,  $V_r$  curve generated from this data by the standard algorithmic procedure - the procedure, a least squares adaptation of form to data, is described in BRL Report 1852<sup>3</sup> and is perhaps most conveniently executed through the use of the BASIC program, "Impact".

Derived parameter values are:

$$V_\ell = 1224 \text{ m/s}, a = 0.82, p = 3.0$$

$S (=24 \text{ m/s})$  is the root mean square error associated with the fit of form to data.

#### 6. Data Sheets:

Completed material data sheets, for target and penetrator, are provided in Tables C-1 and C-2. Tables C-3, C-4, and C-5 contain completed range and radiograph data sheets for the fourth round in the  $V_s$ ,  $V_r$  test (the fourth round being chosen arbitrarily as a source for examples).

VIMVAR-Processed Steel Rods Impacting RHA  
 $v_s$ ,  $v_r$  Curve Derived from Experimental Data by the Standard Procedure

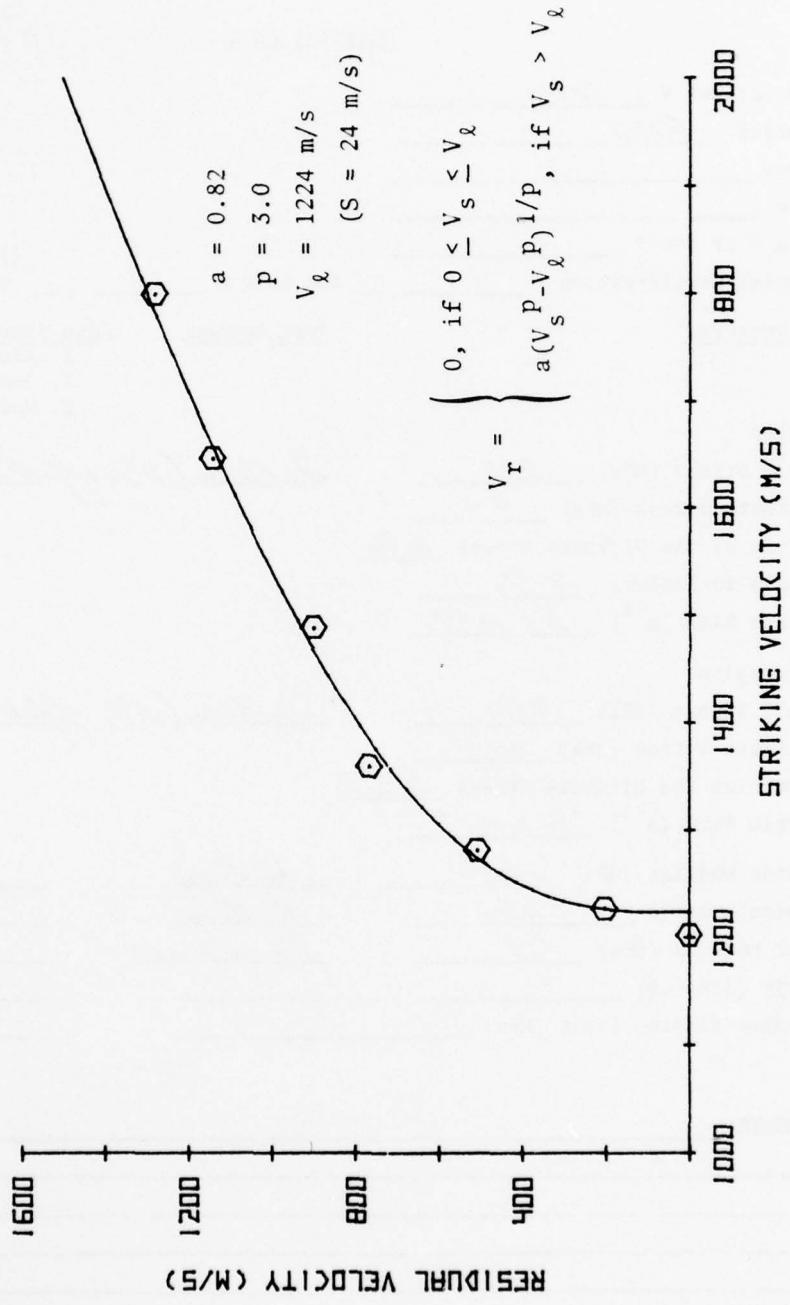


Figure C-2. Experimental Data Points and Derived  $v_s$ ,  $v_r$  Curve

Table C-1. Completed Material Data Sheet for Target

**MATERIAL DATA**

Material Ref # 1000

Material RHA

Source \_\_\_\_\_

Lot # \_\_\_\_\_

Plate # or Bar # \_\_\_\_\_

Material Certification # \_\_\_\_\_

and Source \_\_\_\_\_

(if different from  
manufacturer)

Property

Test Method

Date Source

1. Sample of same lot #.
2. Sample of similar material.
3. Nominal - handbook value.

Tension

Yield Stress (MPa) 825

Instron (2% offset) 2

Ultimate Stress (MPa) 940

Strain at the Ultimate Stress 6%

Strain to Failure 18%

Strain Rate ( $s^{-1}$ )  $3 \times 10^{-4}$

Compression

Yield Stress (MPa) 870

Instron (2% offset) 2

Ultimate Stress (MPa) 1105

Strain at the Ultimate Stress 5.5%

Strain Rate ( $s^{-1}$ )  $3 \times 10^{-4}$

Elastic Modulus (GPa) 20.3

Instron 2

Poisson's Ratio .275

Instron 2

Shear Modulus (GPa) 7.9

Elastometer 2

Charpy (dyne-cm) \_\_\_\_\_

\_\_\_\_\_

Hugoniot Elastic Limit (MPa) \_\_\_\_\_

\_\_\_\_\_

COMMENTS: \_\_\_\_\_

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Table C-2. Completed Material Data Sheet for Penetrator

**MATERIAL DATA**

Material Ref # 10

Material Custom Tool Steel - Vacuum Processed

Source Cartech Corp., Reading, Pa.

Lot # \_\_\_\_\_

Plate # or Bar # \_\_\_\_\_

Material Certification # \_\_\_\_\_ and Source \_\_\_\_\_ (if different from manufacturer)

Property

Test Method

Date Source

1. Sample of same lot #.
2. Sample of similar material.
3. Nominal - handbook value.

**Tension**

Yield Stress (MPa) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Ultimate Stress (MPa) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Strain at the Ultimate Stress \_\_\_\_\_

Strain to Failure \_\_\_\_\_

Strain Rate ( $s^{-1}$ ) \_\_\_\_\_

**Compression**

Yield Stress (MPa) 1796

Instron (2% offset) 1

Ultimate Stress (MPa) 2400

Strain at the Ultimate Stress 3%

Strain Rate ( $s^{-1}$ )  $4.37 \times 10^{-5}$

Elastic Modulus (GPa) 218.25

Instron

1

Poisson's Ratio .286

Electromet

1

Shear Modulus (GPa) 80.8

Electromet

1

Charpy (dyne-cm) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Hugoniot Elastic Limit (MPa) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

COMMENTS: This material differs from AISI S-7 tool steel  
in the (accidental) emission of No.

Table C-3. Completed Range Data Sheet - Before Shot

RANGE DATA SHEET - BEFORE SHOT

Project Engineer P. Lambert Comments: RECOVERY MEDIUM: 21" CELOTEX  
 Project ID ACT - 20" PLYWOOD (1/2" sheets)  
 Range 110 E  
 Gun Caliber .26 Smooth Bore ✓ Rifling  
 Date (month/day/yr) 5/16/76  
 Round # 261 Name  Series 19  
 Type: Experimental ✓ Fielded \_\_\_\_\_  
 Sabot: Discarding  Non-Discarding  None   
 Descriptor Reference # /  
 (detailed drawing and description including stabilizer if applicable)

Projectile  
 Total Mass (g) 64.06 Launch Mass (g) 172.46  
 Total Length (cm) 10.25 Powder Type MP-H2  
 Maximum Diameter (excluding stabilizer) (cm) 1.02 Powder Mass (g) 218

Penetrator  
 Nose Shape HEMISPHERICAL  
 Total Length (cm) 10.25  
 Maximum Diameter (cm) 1.02  

Projectile Part	Mass (g)	Material	Ref. #	Hardness Value	Hardness Test	Density (g/cc)
A. Penetrator Penetrator Parts	<u>64.06</u>	<u>STEEL</u>	<u>10</u>	<u>55</u>	<u>RC</u>	<u>7.83</u>

  
 B. Aerodynamic Shell  
 C. Stabilizer  
 Rate of Spin (rps) \_\_\_\_\_ (if spin stabilized)

Target Plate 1	Target Plate 2	Target Plate 3
Material <u>RHA</u> Ref# <u>1000</u>	Material _____	Material _____
Incidence Angle (deg) <u>60</u>	Incidence Angle (deg) _____	Incidence Angle (deg) _____
Mass (g) <u>8944</u>	Mass (g) _____	Mass (g) _____
Thickness (cm) <u>2.53</u>	Thickness (cm) _____	Thickness (cm) _____
Hardness - Value <u>364</u>	Hardness - Value _____	Hardness - Value _____
- Test <u>BHN</u>	- Test _____	- Test _____
Density (g/cc) <u>7.8</u>	Density (g/cc) _____	Density (g/cc) _____
Type: <u>✓</u> Rect <u>Cir</u>	Type: <u>Rect</u> <u>Cir</u>	Type: <u>Rect</u> <u>Cir</u>
Lgth/Dia (cm) <u>30.0</u>	Lgth/Dia (cm) _____	Lgth/Dia (cm) _____
Width (cm) <u>15.2</u>	Width (cm) _____	Width (cm) _____
	Spacing between plates 1 and 2 (cm) _____	Spacing between plates 2 and 3 (cm) _____

Table C-4, Completed Range Data Sheet - After Shot

**RANGE DATA SHEET - AFTER SHOT**

Project ID	<u>ACT</u>	Comments:	_____		
Round #	<u>261</u>	Series	<u>19</u>		
<u>Recovered Penetrator</u>		Piece 1	Piece 2	Piece 3	_____
Residual Mass (g)		<u>20.7</u>	_____	_____	_____
Residual Length (cm)		<u>3.4</u>	_____	_____	_____
<u>Plug</u>					
Mass (g)	_____				
Length (cm)	_____				
Diameter (cm)	_____				
<u>Target Plate 1</u>					
Mass (g)	<u>8848</u>				
<u>Entrance Hole</u>					
Minimum distance from hole to plate edge (cm)	<u>6.5</u>				
Length (cm)	<u>5.5</u>	Width (cm)	<u>3.0</u>		
Perforation?	Yes <input checked="" type="checkbox"/>	No	_____		
<u>Center Hole</u>					
Length (cm)	<u>2.81</u>	Width (cm)	<u>1.59</u>	Penetration depth (cm)	_____
				Bulge extent, from rear plate surface (cm)	_____
<u>Exit Hole</u>					
Length (cm)	<u>2.5</u>	Width (cm)	<u>2.5</u>	Back surface fracture? Yes	No
<u>Target Plate 2</u>					
Mass (g)	_____				
<u>Entrance Hole</u>					
Minimum distance from hole to plate edge (cm)	_____				
Length (cm)	_____	Width (cm)	_____		
Perforation?	Yes	No	_____		
<u>Center Hole</u>					
Length (cm)	_____	Width (cm)	_____	Penetration depth (cm)	_____
				Bulge extent, from rear plate surface (cm)	_____
<u>Exit Hole</u>					
Length (cm)	_____	Width (cm)	_____	Back surface fracture? Yes	No
<u>Target Plate 3</u>					
Mass (g)	_____				
<u>Entrance Hole</u>					
Minimum distance from hole to plate edge (cm)	_____				
Length (cm)	_____	Width (cm)	_____		
Perforation?	Yes	No	_____		
<u>Center Hole</u>					
Length (cm)	_____	Width (cm)	_____	Penetration depth (cm)	_____
				Bulge extent, from rear plate surface (cm)	_____
<u>Exit Hole</u>					
Length (cm)	_____	Width (cm)	_____	Back surface fracture? Yes	No

Table C-5. Completed Radiograph Data Sheet

**RADIOGRAPH DATA**

Project ID ACT  
 Range 110-E  
 Gun Caliber 26  
 Date (month/day/yr) 5/6/76  
 Round # 261 Series 19  
 File # 504-29-50

Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Projectile  
 Striking Velocity (m/s) 1360.  
 Striking Yaw - Vertical (deg) +0.4  
 (up: +, down: -) ( $\alpha$ )  
 Striking Yaw - Horizontal (deg) +0.7  
 (right: +, left: -) ( $\beta$ )  
 Total Yaw - ( $\delta$ ) (deg) 0.8

Plug (if applicable)  
 Velocity (m/s) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_  
 Diameter (cm) \_\_\_\_\_  
 Trajectory -  
 Cone Angle ( $\lambda$ ) (deg) \_\_\_\_\_  
 Phase Angle ( $\phi$ ) (deg) \_\_\_\_\_

Phase Angle ( $\phi$ ) (deg) \_\_\_\_\_

Penetrator, Residual

Plate 1  
 Velocity (m/s) 769  
 Mass (g) 22.4\*  
 Length (cm) 3.6\*  
 Trajectory -  
 Cone Angle ( $\lambda$ ) (deg) 23  
 Phase Angle ( $\phi$ ) (deg) 6  
 Vertical Yaw Rate (rev/sec) 902

Piece 1  
 Piece 2  
 Piece 3

Plate 2  
 Velocity (m/s) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_  
 Trajectory -  
 Cone Angle ( $\lambda$ ) (deg) \_\_\_\_\_  
 Phase Angle ( $\phi$ ) (deg) \_\_\_\_\_  
 Vertical Yaw Rate (rev/sec) \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Plate 3  
 Velocity (m/s) \_\_\_\_\_  
 Mass (g) \_\_\_\_\_  
 Length (cm) \_\_\_\_\_  
 Trajectory -  
 Cone Angle ( $\lambda$ ) (deg) \_\_\_\_\_  
 Phase Angle ( $\phi$ ) (deg) \_\_\_\_\_  
 Vertical Yaw Rate (rev/sec) \_\_\_\_\_

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

\*The discrepancies between the actual mass and length of the recovered penetrator (in Table C-4) and the calculated mass and length measured on the radiograph are due primarily to the deformed condition of a residual penetrator whose jagged ends yield different lengths.

APPENDIX D

Predictive Model

## APPENDIX D

### Predictive Model

A method is provided for predicting the limit velocity and  $V_s$ ,  $V_r$  relationship for situations involving the impact of "long-rod" penetrators\* on single plate targets of rolled homogeneous armor (RHA) or aluminum (Al). An elaboration of these formulations will be forthcoming<sup>5</sup>.

Input parameters; it is assumed that the following values are known:

$M$  - penetrator mass, in grams

$L$  - penetrator length, in centimeters

$D$  - penetrator diameter, in centimeters

$T$  - target thickness, in centimeters

$\rho$  - target material density, in  $\text{g/cm}^3$

$\theta$  - incidence angle

Now let:  $z = \frac{T}{D} (\sec \theta)^{3/4}$

$$f(z) = z + e^{-z} - 1 \quad \left( = \sum_{k=2}^{\infty} \frac{(-z)^k}{k!} \right)$$

$$m = \frac{\rho}{4} \pi D^3 z$$

$$a = \frac{M}{M + m/3}$$

$$p = 2 + z/3$$

$$u = \begin{cases} 4,000 & \text{RHA target} \\ 1750 & \text{Al target} \end{cases} \quad (u^2 \text{ has the dimension of stress})$$

<sup>5</sup>J. P. Lambert, "A Residual Velocity Predictive Model for Long Rod Penetrators", to appear.

\*We have in mind penetrators which are essentially cylindrical solids with length to diameter ratio in excess of 4.

The predicted limit velocity, in meters per second, is then:

$$V_{\ell} = u \left( \frac{L}{D} \right)^{15} \sqrt{f(z) \cdot \frac{D^3}{M}}$$

and the anticipated  $V_s$ ,  $V_r$  curve is specified by:

$$V_r = \begin{cases} 0, & 0 \leq V_s \leq V_{\ell} \\ a(V_s^p - V_{\ell}^p)^{1/p}, & V_s > V_{\ell} \end{cases}$$

Remark: With less assurance (because of little experience to date) we propose these formulae might also be used to describe the penetration of fragments into RHA or aluminum. Supposing the material density of the fragment to be  $\rho_0$  g/cc and its presented area (the known or expected area projected by the fragment along the line of flight into the target surface at impact) to be  $A$  ( $\text{cm}^2$ ), let

$$D = 2\sqrt{A/\pi} \quad \text{and} \quad L = \frac{M}{A\rho_0},$$

and predict according to the preceding equations.

## APPENDIX E

### Sample Range Checklist

We strongly recommend that a complete set of range instructions be available and utilized. As an example, the following is a checklist for the BRL Terminal Ballistics Division Ranges 110E and 110G. We are grateful to Mr. Giglio-Tos of TBD for its compilation.

## RANGE PROCEDURE FOR RANGES 110E & G

### Before Shot:

- 1. Fill out RANGE DATA SHEET BEFORE SHOT.
- 2. Draw diagram of range setup if this is first shot in program or if setup has changed.
- 3. Turn on delayed trigger amplifiers.
- 4. Turn on counters.
- 5. Turn on Thyratron trigger.
- 6. Install target.
- 7. Install trigger break screen.
- 8. Install sabot stripper.
- 9. Install film cassettes, add protective covers.
- 10. Replace fiducial wires if necessary and make other repairs.
- 11. Attach leaded numbers indicating stations used.
- 12. Set up and number fragment recovery materials as appropriate.
- 13. Assemble projectile and sabot, load at bottom of forcing cone.
- 14. Insert correct amount of delay time in delayed trigger amplifiers. Record times on RANGE WORK SHEET.
- 15. Turn on trigger screen voltage.
- 16. Close target room door and blast room door.
- 17. Weigh appropriate powder charge, put powder in case and load gun.
- 18. Perform static timing test and record times on RANGE WORK SHEET
- 19. Close breech.
- 20. Connect firing line.
- 21. Close gun room door.
- 22. Close heat ducts.
- 23. Connect safety interlock (red light above door should light up).
- 24. Connect 110 VAC.
- 25. Turn on firing power supply switch.
- 26. Blow siren 3 times.
- 27. Fire gun.

### After Shot:

- 28. Record actual time delays from delayed trigger amplifier counters on RANGE WORK SHEET.
- 29. Blow siren once (1) for all clear.
- 30. Disconnect safety interlock.
- 31. Turn off firing power supply.
- 32. Disconnect 110 VAC.
- 33. Disconnect firing line and lock line in safety box.
- 34. Open gun room door.
- 35. Turn on exhaust fan.
- 36. Clear gun (remove firing mechanism and firing plug).
- 37. Open blast room and target room doors.
- 38. Turn off trigger screen voltage (90V battery).
- 39. Remove target and record measurements on RANGE DATA SHEET AFTER SHOT.
- 40. Save at least one target plate/program.
- 41. Remove films, punch project ID and round number into films.
- 42. Record film measurements on RANGE WORK SHEET.
- 43. Recover principal penetrator pieces and possible plug.
- 44. Record their measurements on RANGE DATA SHEET AFTER SHOT.
- 45. Recover other fragments if applicable.
- 46. Clean range.
- 47. Clean gun.
- 48. Read film to determine correct powder charge for next shot to conform to  $V_s$ ,  $V_r$  curve.

## APPENDIX F

### Program Listing of "Augur"

A program, in BASIC, to predict (and represent graphically) limit velocity and the  $V_s$ ,  $V_r$  relationship for situations involving the impact of "long rod" penetrators into single RHA or aluminum plates; the test sequence of preliminary striking velocities can be generated as an option.

```

120 REM----- AUGUR
120 REM----- THE PROGRAM GENERATES PREDICTED VALUES FOR THE PARAMETERS A, P, UL
120 REM----- (OF THE "STANDARD" US, UR FORM) AND THE US, UR CURVE IF DESIRED.
130 REM----- (THE CURVE ALONE CAN BE GENERATED IF A,P,UL ARE ALREADY KNOWN).
140 REM----- IT IS SUPPOSED THAT THE SITUATION INVOLVES THE IMPACT OF A "LONG ROD"
150 REM----- PENETRATOR (L/D)<4.5) HAVING HEMISPHERICAL NOSE ONTO A SINGLE RHA OR
160 REM----- ALUMINUM TARGET PLATE.
170 REM----- THE PREDICTIVE SCHEME REQUIRES AS INPUT THE TARGET THICKNESS (CM),
180 REM----- INCIDENCE ANGLE (DEG), PENETRATOR DIAMETER (CM) & TWO OF THE FOLLOWING:
190 REM----- PENETRATOR MASS (G), L/D, AVERAGE PENETRATOR DENSITY (G/CC).
200 REM----- THE "AUTOMATIC SCALING" OPTION PROVIDES REASONABLE PLOTTING DISPLAY
210 REM----- IN MOST SITUATIONS ANTICIPATED.
220 REM----- OPERATIVE EQUATIONS:
230 REM----- LET Z=T/(DX(COS(IA))^.75), F(Z)=Z+EXP(-Z)-1, M'=R*PIX*D/4 (GRAMS)
240 REM----- A=M/(M+M^.3), P=Z^2/3, UL=C-K*(L/D)^.15*SQR(F(Z)*D^.3/M) (M/S),
250 REM----- WHERE, FOR RHA: R=7.8 & K=4000, FOR ALUMINUM: R=2.74 & K=1750.
260 REM----- THEN, FOR 0<US<UL: UR=A*(US-P-ULP)^(1/P) (M/S).
270 REM----- INPUT A,P,C
280 INPUT A,P,C
290 GOTO 630
300 DISP "RHA OR AL. TARGET (R OR A) ";
310 INPUT A
320 IF A=.R. THEN 350

```

```

330 B=1750
340 B5=2.74
350 DISP . DIAMETER (CM) ;
360 INPUT N2
370 DISP . PEN. MASS (G), (0 IF UNKNOWN) ;
380 INPUT N1
390 IF N1 THEN 420
400 DISP . L/D = " ;
410 INPUT N5
420 DISP . TARGET THICKNESS (CM) ;
430 INPUT N3
440 DISP . INCIDENCE ANGLE ;
450 INPUT N4
460 IF N1=0 THEN 510
470 DISP . L/D = "(0 IF UNKNOWN) " ;
480 INPUT N5
490 N6=4*N1/(PI*XN2^3*(N5-1/6))
500 IF N5 THEN 570
510 DISP . PENETRATOR DENSITY (G/CC) ;
520 INPUT N6
530 IF N1 THEN 560
540 N1=PI*XN2^3*XN6*(N5-1/6)/4
550 GOTO 570
560 N5=4*N1/(PI*XN2^3*XN6)+1/6
570 Q=N3/N2*(COSN4)^(-0.75)
580 A=N1/(N1+PI*XN2^3*XQ*XN5/12)
590 P=2+Q/3
600 C=B*XN5^0.15*SQR(N2^3/N1^(Q-1+EXP(-Q)))
610 WRITE (15,1980)N1,N2,N3,N4,N5,
620 WRITE (15,1990)N6
630 WRITE (15,2000)A,P,C
640 P1=1/P
650 C1=C^P

```

```

660 DISP • PLOT ( Y OR N ) ";
670 INPUT AS
680 IF AS=="N." THEN 1550
690 J=U=1
700 DISP • AUTOMATIC SCALING ( Y OR N ) ";
710 INPUT AS
720 IF AS=="Y." THEN 780
730 U=0
740 DISP • DRAW & LABEL AXES ( Y OR N ) ";
750 INPUT AS
760 DISP • MIN ON US AXIS ( <"INTC">) ;
770 INPUT X3
780 DISP • MAX ON US AXIS ( >"1+INTC") ;
790 INPUT X4
800 Z=AX(X4^P-C1)^P1
810 IF AS=="N." THEN 860
820 O=1
830 IF U THEN 920
840 DISP • INTERVAL SPACING ON US AXIS ";
850 INPUT D
860 DISP • MAX ON UR AXIS ( >"INTZ") ;
870 INPUT Y1
880 IF O=0 THEN 970
890 DISP • INTERVAL SPACING ON UR AXIS ";
900 INPUT E
910 GOTO 970
920 D=50+50*((X4-C)>200)+100*((X4-C)>400)
930 E=2XD
940 Q=D*XINT(C/D)
950 X3-Q-((C-Q)*(50))*D/2
960 Y1-E+EXINT(Z/E)
970 Q=X4-X3
980 M1=X3-Q/4

```

```

990 M2=X4+Q/8
1000 M3=-Y1/3
1010 M4=1.25XY1
1020 M5=100/(M2-M1)
1030 M6=70/(M4-M3)
1040 X9=-Q/30
1050 SCALE M1,M2,M3,M4
1060 LABEL (*,1.6,1.7,0,0.7)
1070 IF O=0 THEN 1260
1080 LABEL (*,1.6,1.7,90,0.7)
1090 PLOT X3-Q/9,0.22XY1,1
1100 LABEL (*)-RESIDUAL VELOCITY (M/S)
1110 YAXIS X3,E/2,0,Y1
1120 XAXIS 0,D/2,X3,X4
1130 LABEL (*,1.6,1.7,0,0.7)
1140 FOR I=X3 TO X4 STEP D
1150 PLOT I,0,1
1160 CPLOT -2.5,-1.5
1170 LABEL (*)I
1180 NEXT I
1190 PLOT X3+Q/3,-0.133XY1,1
1200 LABEL (*)-STRIKING VELOCITY (M/S)
1210 FOR I=E TO Y1 STEP E
1220 PLOT X3-Q/11,I,1
1230 CPLOT 0,-0.3
1240 LABEL (2020)I
1250 NEXT I
1260 Z=AX(X4^P-C1)^P1
1270 Z0=Y1+(Z-Y1)*(Z(Y1))
1280 E0=Z0/40
1290 FOR I=0 TO Z0 STEP E0
1300 PLOT ((I/A)^P+C1)^P1,I
1310 NEXT I

```

```

1320 PEN    • DRAW ASYMMTOE ( Y OR N ) " ;
1330 INPUT AS
1340 IF AS = 'N' THEN 1420
1350 FOR I=X4+X9 TO X3 STEP X9
1360 Y=AXI
1370 IF Y>Y1 THEN 1410
1380 PLOT I,Y
1390 PEN
1400 NEXT I
1410 SCALE 0,100,0,70
1420 DISP • PRINT A, P, UL ( Y OR N ) " ;
1430 INPUT AS
1440 IF AS = 'N' THEN 1550
1450 PLOT 75,25,1
1460 LABEL (2010)A,P,C
1470 CPLOT 0,0,5
1480 LABEL (X),L
1490 PLOT 89.5,17
1500 PLOT 89.5,28
1510 PLOT 89.5,28
1520 PLOT 73,28
1530 PLOT 73,17
1540 PLOT 89.5,17,-1
1550 DISP 'GENERATE TEST SEQ. ( Y OR N ) " ;
1560 INPUT AS
1570 IF AS = 'Y' THEN 2040
1580 DISP 'GET POINTS ON CURVE ( Y OR N ) " ;
1590 INPUT AS
1600 IF AS = 'N' THEN 1630
1610 WRITE (15,1960)
1620 GOSUB 1+(J=0) OF 2160,2430
1630 IF J=0 THEN 1940
1640 DISP 'PLOT OTHER POINTS ( Y OR N ) " ;

```

```

1650 INPUT AS
1660 IF AS = "N" THEN 1690
1670 WRITE (15,1960)
1680 GOSUB 2160
1690 SCALE 0,100,0,70
1700 DISP "DRAW BORDER ( Y OR N ) ";
1710 INPUT AS
1720 IF AS = "N" THEN 1780
1730 PLOT 0,0,0
1740 PLOT 0,70,2
1750 PLOT 100,70
1760 PLOT 100,0
1770 PLOT 0,0,-1
1780 DISP "UPPER TITLE, LINE 1 (N IF NONE) ";
1790 INPUT AS
1800 IF AS = "N" THEN 1880
1810 PLOT 50-LEN(AS)/2,66,0
1820 LABEL (X)AS
1830 DISP "UPPER TITLE, LINE 2 (N IF NONE) ";
1840 INPUT AS
1850 IF AS = "N" THEN 1880
1860 PLOT 50-LEN(AS)/2,63,0
1870 LABEL (X)AS
1880 DISP " LOWER TITLE (ENTER N IF NONE) ";
1890 INPUT AS
1900 IF AS = "N" THEN 1930
1910 PLOT 50-LEN(AS)/2,3,0
1920 LABEL (X)AS
1930 PLOT 0,0,0
1940 WRITE (15,2030)
1950 END
1960 FORMAT '13X,"US" 8X,"UR",/,12X,4"-",6X,4"-"
1970 FORMAT F16.0,F10.0

```

```

1980 FORMAT /, 'M=' , F7.1, '5X, "D=" , F5.2, '5X, "T=" , F6.2, '5X, "IA=" , F3.0, '5X, "L/D=" , F5.1
1990 FORMAT 5X, 'R=' , F6.2, /
2000 FORMAT 20X, 'A=' , F5.2, /
2010 FORMAT 'A=' , F5.2, /, 'P=' , F4.1, " , 'U=' , F5.0, " , 'UL=' , F5.0, /
2020 FORMAT F5.0
2030 FORMAT 80
2040 DISP 'TOTAL NO. OF ROUNDS AVAILABLE ';
2050 INPUT N
2060 N8=N-2
2070 N9=N8-1
2080 DISP ' MAXIMUM ATTAINABLE US ';
2090 INPUT X
2100 C0=CXC
2110 C9=XXX-C0
2120 PRINT " SUGGESTED STRIKING VELOCITY SEQUENCE FOR THE FIRST 'N'8
2130 PRINT " ROUNDS, WITH ANTICIPATED CORRESPONDING RESIDUAL VELOCITIES."
2140 PRINT " (TWO SHOTS ARE AVAILABLE FOR POSSIBLE LATER USE) ::"
2150 IF J=0 THEN 2720
2160 DISP 'SIDES/SYMBOL (OR 0=NONE, 1=STAR)';
2170 INPUT N0
2180 Q=Q9-Q
2190 Q9=0
2200 IF N0=0 THEN 2420
2210 IF N0#4 THEN 2260
2220 DISP ' SQUARES OR DIAMONDS (S OR D) ';
2230 INPUT AS
2240 IF AS=.D. THEN 2310
2250 O0=45
2260 IF N0#1 THEN 2290
2270 N0=10
2280 Q9=-0.4
2290 IF N0>0 AND N0<30 THEN 2310
2300 N0=30

```

```

2310 DISP ' SYMBOL SIZE: L, M, OR S ';
2320 INPUT AS
2330 07=08=(POS(AS,"L")=1)+0.8*(POS(AS,"M")=1)+0.6*(POS(AS,"S")=1)
2340 N0=360/N0
2350 FOR 0.00 TO 00+370 STEP N0
2360 Q=Q+1
2370 IF Q9=0 THEN 2390
2380 08=07X(1+Q9X(-1)^Q)
2390 MC0,1J=COS0*X08
2400 MC0,2J=SIN0*X08
2410 NEXT C
2420 IF N#0 THEN 2720
2430 IF J#0 THEN 2460
2440 DISP "US (E FOR END) ";
2450 GOTO 2470
2460 DISP "US (E FOR END, N FOR NEW SYMBOL) ";
2470 INPUT AS
2480 IF AS="E" THEN 2700
2490 IF AS="N" THEN 2160
2500 X=VAL(AS)
2510 IF I=0 THEN 2550
2520 DISP "UR";
2530 INPUT Y
2540 GOTO 2580
2550 Y=0
2560 IF X <= C THEN 2580
2570 Y=AX(X^P-C1)^P1
2580 WRITE (15,1970)X,Y
2590 IF N#0 THEN 2610
2600 IF J=0 THEN 2430
2610 IF J=0 THEN 2700
2620 OFFSET MSX(X-M1),MSX(Y-M1)
2630 PLOT 0,0

```

```
2640 PEN
2650 FOR K=1 TO 0
2660 PLOT MCK,1J,MCK,2J
2670 NEXT K
2680 PEN
2690 IF N=0 THEN 2430
2700 RETURN
2710 END
2720 WRITE (15,1960)
2730 GOSUB 2570
2740 FOR I=2 TO N8-1
2750 X=SQR(C0+((N8-I)/N9)^2*C9)
2760 GOSUB 2570
2770 NEXT I
2780 X=C
2790 Y=0
2800 GOSUB 2580
2810 PRINT
2820 GOTO (1+J) OF 1940,1690
2830 REM--- 8/1/77 ---
```

## APPENDIX G

### Program Listing of "Impact"

A program, in BASIC, for the derivation and graphic representation of limit velocity and the  $V_s$ ,  $V_r$  relationship. Required input is a set of experimental  $V_s$ ,  $V_r$  data related to a fixed penetrator/target set-up.

```

10 REM IMPACT - FOR A GIVEN SET OF US, UR DATA THE PROGRAM GENERATES ESTIMATES FOR THE
20 REM PARAMETERS A, P, AND UL (OF THE 'STANDARD' US,UR FORM) AND THE US,UR CURVE
30 REM IF DESIRED. (THE CURVE ALONE CAN BE GENERATED IF A,P,UL ARE ALREADY
40 REM KNOWN). THE PROCEDURE ADAPTS THE FORM TO EXPERIMENTAL DATA USING A
50 REM SLIGHT MODIFICATION OF THE OPTIMIZATION SCHEME DESCRIBED IN BRLR 1852.
60 REM COMPLETE SETS OF US,UR DATA SHOULD BE USED (INCLUDING NON-PERFOR-
70 REM ATIONS, FOR WHICH UR=0). THERE MUST BE AT LEAST 2 DATA PAIRS AND AT
80 REM LEAST ONE PERFORATION (UR>0) FOR THE PROCEDURE TO BE USED.
90 REM THE LAST VALUES PRINTED FOR A,P,C (=UL),S ARE THE DERIVED ESTIMATES
100 REM FOR THESE PARAMETERS. S IS THE RMS ERROR OF THE FIT.
110 REM TO CORRECT THE ENTRY OF A DATA PAIR, INPUT 'R' WHEN ASKED FOR US OR
120 REM UR, AND RE-ENTER VALUES AS INDICATED.
130 REM THE 'AUTOMATIC SCALING' OPTION PROVIDES FOR REASONABLE PLOTTING
140 REM DISPLAY IN MOST SITUATIONS ANTICIPATED.
150 REM THERE IS AN OPTION TO DRAW 'BANDS' - THESE ARE CURVES WHICH, FOR AN
160 REM INPUT X OF PARAMETER VARIATION, OUTLINE THE REGION FORMED BY ALLOWING
170 REM EACH OF THE 3 PARAMETERS (A,P,UL) TO VARY BY THE SPECIFIED PERCENTAGE.
180 REM
190 REM
200 DEG
210 DIM U[15],P[15],M[15],S[15]
220 DISP 'A,P,UL TO BE DERIVED (Y OR N) ?'
230 INPUT AS
240 IF AS='Y' THEN 310
250 DISP 'THEN A,P,UL ARE KNOWN: ENTER THEM '
260 INPUT A,P,C
270 X1=X2-C
280 P1=P-1/P
290 C1=C^P
300 GOTO 1500
310 WRITE '(15,1410)'
320 Q2=C*G1*B1-B2*B3-B4*B5-B6*B7-B8*B9
330 P=2
340 FOR I=1 TO 201
350 IF I>2 THEN 380

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```

360 DISP "US,I";
370 GOTO 390
380 DISP "US,I"(ENTER F WHEN FINISHED");
390 INPUT AS
390 IF AS="F" THEN 510
400 IF AS="R" THEN 440
410 IF AS="L" THEN 440
420 I=I-1
430 GOTO 350
440 UC1,13=VAL(AS)
450 DISP "UR,I",
460 INPUT AS
470 IF AS="R" THEN 350
480 UC1,22=VAL(AS)
490 WRITE (15,1420)(UC1,12,UC1,22)
500 NEXT I
510 N=I-1
520 REDIM UCN,22
530 SORT U,C,1,2
540 Q1=N
550 FOR I=1 TO N
560 Q1=Q1+(1-Q1)*(UC1,12)-(UC1,22)*(
570 Q2=Q2+(I-Q2)*(UC1,12)-(UC1,22)*(
580 NEXT I
590 FOR I=Q1 TO N
600 Y0=Y0+(UC1,22)*Y0*(UC1,22)*(
610 UC1,12)+(UC1,22)*Y0*(UC1,22)*(
620 M=UC1,12*UC1,22
630 B1=B1+UC1,22
640 B2=B2+UC1,22
650 B3=B3+M
660 B4=B4+UM
670 NEXT I
680 R=N+1-Q1
690 WRITE (15,1430)
700 G2=UC01,12

```

```

719 IF Q2=0 THEN 740
720 G1=U*Q1,1JX(Q1 < 0 Q2)+U*Q2,1JX(Q1>Q2)
730 G2=U*Q1,1JX(Q1 > - Q2)+U*Q2,1JX(Q1<Q2)
740 Z1=RXB1-B2XB2
750 IF Z1=0 THEN 810
760 U=(RXB4-B2XB3)/21
770 Z2=B2XU-B3
780 IF Z2 < 0 THEN 810
790 C=INTSQR(Z2/R/U)
800 IF G1 < 0 AND C < 0 G2 THEN 820
810 C=G1X(C<G1)+G2X(C>G2)
820 GOSUB 1180
830 WRITE (15,1440)A0,P,C,SQRABS((B3-U)/N)
840 GOSUB 1030
850 W2=U
860 GOSUB 1360
870 J=0.1+0.1X(P)= 4
880 P=P+J
890 GOSUB 1030
900 IF U>U1 AND P<8.1 THEN 860
910 P=P-J
920 GOTO 1+(U1-U2) OF 980,940
930 GOSUB 1360
940 P=P-0.1
950 GOSUB 1030
960 IF U>U1 AND P>1 THEN 930
970 P=P+0.1
980 WRITE (15,1450)
990 DISP . PLOT DESIRED ( Y OR N ) ,;
1000 INPUT AS
1010 IF AS=.Y. THEN 1460
1020 END
1030 Z2=U
1040 Z1=U
1050 C=C+1
1060 GOSUB 1180

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1070 IF U>Z1 THEN 1040
1080 C=C-1
1090 GOTO 1+(Z1-Z2) OF 1160,1110
1100 Z1=U
1110 IF C=0 THEN 1160
1120 C=C-1
1130 GOSUB 1180
1140 IF U>Z1 THEN 1160
1150 C=C+1
1160 U=Z1
1170 RETURN
1180 H=G-F*L*G
1190 C1=C^P
1200 P1=1/P
1210 FOR I=1 TO N
1220 IF U<I,1>C THEN 1280
1230 IF U<I,2>0 THEN 1270
1240 T=(C1-U<I,1>P)^P1
1250 F=F+T*T
1260 L=L-U<I,2>*T
1270 NEXT I
1280 FOR I=1 TO N
1290 T=(U<I,1>P-C1)^P1
1300 H=H+T*T
1310 G=G+U<I,2>*T
1320 NEXT I
1330 A0=(G )= H)+(G<H>)*G/H
1340 U=2XA0*X(G+L)-A0XA0*X(H+F)
1350 RETURN
1360 U1=U
1370 A=A0
1380 S=SQRABSS((B3-U)/N)
1390 WRITE (15,1440)A,P,C,S
1400 RETURN
1410 FORMAT 13X,'US',8X,'UR','/,12X,4'-'',6X,4'-''
1420 FORMAT F16.0,F10.0
1430 FORMAT 1,8X,'A',9X,'P','/9X,'C',13X,'S','/6X,4'-'',7X,3'-'',6X,4'-'',9X,6'-''

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```

1440 FORMAT F10.2,F10.1,F10.0,F15.1
1450 FORMAT 50.,/,/
1460 P1=1/P
1470 C1=C^P
1480 X1=CX(C,-UE1,12)+UE1,12*(C>UE1,12)
1490 X2=UE1,12
1500 IF B$0 THEN 1660
1510 DISP . AUTOMATIC SCALING ( Y OR N ) ,
1520 INPUT AS
1530 0-1
1540 IF AS=="N" THEN 1660
1550 Q=X2-X1
1560 D=50+50*(Q>200)+100*(Q>400)
1570 E=2*D
1580 Q=D*XINT(X1/D)
1590 X3=Q-((X1-Q)<(50)*(X>D/2)
1600 X4=D*XINT(X2/D)+D
1610 Z=AX(X4,P-C1)*P1
1620 Q=Z+(Y0-Z)*(Y0>Z)
1630 Y1=E*XINT(Q/E)+E
1640 GOTO 1860
1650 Z=AX(X4^P-C1)^P1
1660 DISP . DRAW & LABEL AXES ( Y OR N ) ,
1670 INPUT AS
1680 O=(POS(AS,"Y")=1)
1690 DISP . MIN ON US AXIS ( <'INTX1' ) ;
1700 INPUT X3
1710 DISP . MAX ON US AXIS ( >'X2' );
1720 INPUT X4
1730 IF X3<X1 OR X4<X2 THEN 1690
1740 IF O=0 THEN 1770
1750 DISP . INTERVAL SPACING ON US AXIS ;
1760 INPUT D
1770 Q=Z-AX(X4^P-C1)^P1
1780 IF B$0 THEN 1860
1790 Q=Z+(Y0-Z)*(Y0>Z)
1800 DISP . MAX ON US AXIS ( >'INTQ' );

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1810 INPUT Y1
1820 Z0=Y1
1830 IF 0=0 THEN 1860
1840 DISP 'INTERVAL SPACING ON UR AXIS :'
1850 INPUT E
1860 Q=X4-X3
1870 M1=X3-Q/4
1880 M2=X4+Q/8
1890 M3=-Y1/3
1900 M4=1.25XY1
1910 M5=100/(M2-M1)
1920 M6=70/(M4-M3)
1930 X7=X3-Q/11
1940 X9=-Q/20
1950 SCALE M1,M2,M3,M4
1960 LABEL (X,1.6,1.7,0,0.7)
1970 IF 0=0 THEN 2160
1980 LABEL (X,1.6,1.7,90,0.7)
1990 PLOT X3-Q/9,0.22XY1,1
2000 LABEL (X)'RÉSIDUAL VÉLOCITÉ (M/S)'
2010 YAXIS X3,E/2,0,Y1
2020 XAXIS 0,D/2,X3,X4
2030 LABEL (X,1.6,1.7,0,0.7)
2040 FOR I=X3 TO X4 STEP D
2050 PLOT I,0,1
2060 CPLOT -2.5,-1.5
2070 LABEL (X)I
2080 NEXT I
2090 PLOT X3+Q/3,-0.133XY1,1
2100 LABEL (X)'STRIKING VÉLOCITÉ (M/S)'
2110 FOR I=E TO Y1 STEP E
2120 PLOT X7,I,1
2130 CPLOT 0,-0,3
2140 LABEL (3160)I
2150 NEXT I
2160 IF B#0 THEN 2530
2170 DISP 'SIDES/SYMBOL (OR 0=NONE, 1=STAR)';

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2180 INPUT NO
2190 J=09=0
2200 09-99
2210 IF NO=0 THEN 2410
2220 IF NO<4 THEN 2270
2230 DISP " SQUARES OR DIAMONDS (S OR D) ";
2240 INPUT AS
2250 IF AS="D" THEN 2310
2260 09-45
2270 IF NO<1 THEN 2300
2280 NO=10
2290 Q9=-0.4
2300 NO=30+(NO-30)*(NO>0) AND (NO<30)
2310 DISP " SYMBOL SIZE: L, M, OR S ";
2320 INPUT AS
2330 07-08-(POS(AS,"L")-1)+0.8*(POS(AS,"M")-1)+0.6*(POS(AS,"S")-1)
2340 FOR 0-0 TO 00+365 STEP 360/NO
2350 J=J+1
2360 IF Q9=0 THEN 2380
2370 08-07X(1+09X(-1)^JJ)
2380 MCJ,1J-COS0X08
2390 MCJ,2J-SIN0X08
2400 NEXT 0
2410 SCALE 0,100,0,70
2420 FOR I=1 TO N
2430 OFFSET NSX(UCI,1J-M1),NSY(UCI,2J-M3)
2440 PLOT 0,0
2450 PEN
2460 FOR K=1 TO J
2470 PLOT MCJ,1J,MCK,2J
2480 NEXT K
2490 PEN
2500 NEXT I
2510 SCALE M1,M2,M3,M4
2520 Z0-Y1+(Z-Y1)*(Z-Y1),
2530 Y=Z0/40
2540 J=1

```

```

2550 FOR I=0 TO Z0 STEP Y
2560 U=MCI,1J-((I/A)^P+C1)^P1
2570 MCI,2J=I
2580 IF U> X4 THEN 2610
2590 J=J+1
2600 NEXT I
2610 FOR I=1 TO J-1
2620 PLOT MCI,1J,MCI,2J
2630 NEXT I
2640 PEN
2650 DISP . DRAW ASYMMTOE ( Y OR N ) ;
2660 INPUT AS
2670 IF AS=.N. THEN 2740
2680 FOR I=X4+X9 TO X3 STEP X9
2690 Y9=AXI
2700 IF Y9>Y1 THEN 2730
2710 PLOT I,Y9
2720 PEN
2730 NEXT I
2740 SCALE 0,100,0,70
2750 IF B=0 THEN 2780
2760 DISP . PRINT A, P, UL ( Y OR N ) ;
2770 GOTO 2790
2780 DISP .PRINT A,P,UL,S ( Y OR N ) ;
2790 INPUT AS
2800 IF AS=.N. THEN 2870
2810 PLOT 75,27,1
2820 LABEL (3170)A,P,C
2830 CPLOT 0,0,6
2840 LABEL (x)=L'
2850 IF B<0 THEN 2870
2860 LABEL (3180)S
2870 DISP . DRAW BANDS ( Y OR N ) ;
2880 INPUT AS
2890 IF AS=.Y. THEN 3200
2900 SCALE 0,100,0,70
2910 DISP . DRAW BORDER ( Y OR N ) ;

```

```

2920 INPUT AS
2930 IF AS=.N. THEN 2990
2940 PLOT 0,0,0
2950 PLOT 0,70,2
2960 PLOT 100,70
2970 PLOT 100,0
2980 PLOT 0,0,-1
2990 DISP 'INPUT UPPER TITLE 1 (N IF NONE) ';
3000 INPUT AS
3010 IF AS=.N. THEN 3090
3020 PLOT 50-0.625*LEN(AS),66,0
3030 LABEL (3470)AS
3040 DISP 'INPUT UPPER TITLE 2 (N IF NONE) ';
3050 INPUT AS
3060 IF AS=.N. THEN 3090
3070 PLOT 50-0.625*LEN(AS),63,0
3080 LABEL (3470)AS
3090 DISP 'INPUT LOWER TITLE (N IF NONE) ';
3100 INPUT AS
3110 IF AS=.N. THEN 3140
3120 PLOT 50-0.625*LEN(AS),3,0
3130 LABEL (3470)AS
3140 PLOT 0,0,0
3150 END
3160 FORMAT F5.0
3170 FORMAT ' A.' ,F5.2,'/' ,P=','F4.1,'/' ,U=','F5.0,' M/S'
3180 FORMAT '(S.' ,F4.0,' M/S)'
3190 DISP ' PERCENT PARAMETER VARIATION ';
3200 INPUT U9
3210 U8=1+U9/100
3220 U9=2-U8
3230 Q=AXU8
3240 A@=Q*(Q<1)+(Q >= 1)
3250 P@=PXU8
3260 C@=CXU8
3270 WRITE (15,3450)A@,P@,C@
3280 GOSUB 3350

```

```
3290 A0=AXU9
3290 P0=PXU9
3310 C0=CXU8
3320 WRITE (15,3460)A0,P0,C0
3330 GOSUB 3350
3340 GOTO 2860
3350 P1=1/P0
3360 C1=C0^P0
3370 SCALE M1,M2,M3,M4
3380 FOR I=0 TO 20 STEP Y
3390 X=((I/A0)^P0+C1)^P1
3400 IF X>X4 THEN 3420
3410 PLOT X,I
3420 NEXT I
3430 PEN
3440 RETURN
3450 FORMAT /,'A1','F5.2,' P1='F5.2,' C1='F5.0'
3460 FORMAT 'A2','F5.2,' P2='F5.2,' C2='F5.0,'/
3470 FORMAT F1.0
3480 REM-----8/1/77-----
```

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